NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

PANORAMIC AUGMENTED REALITY FOR PERSISTENCE OF INFORMATION IN COUNTERINSURGENCY ENVIRONMENTS (PARPICE)

by

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December 2010

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** December 2010	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE Panoramic Augmented Reality for Persistence of Information in Counterinsurgency Environments (PARPICE)			**5. FUNDING NUMBERS**
6. AUTHOR(S) Brett D. Lindberg			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) JIEDDO; HQDA G-8 CAA			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES 11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number ____N.A.__________.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; public distribution is unlimited			**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

Modern Counter-Insurgency (COIN) and Irregular Warfare (IW) are increasingly complex. Contributing to this complexity is the need to develop and maintain a mental map of relevant environmental and historical factors and their interactions, generated from disparate sources of information that must be organized, processed and integrated. Compounding this challenge is the fact that mental pictures cannot easily be passed from one soldier to the next. This is a problem when the tactical situation dictates frequent changes in unit Areas of Operations (AOs), and particularly in cases where units rotate on a regular basis. When units hand over an AO, the incoming unit must quickly rebuild a mental picture and narrative of its operating environment. Because of this, historical organizational knowledge is lost that could otherwise increase combat effectiveness and reduce casualties.

This thesis discusses a prototype architecture for a system that will enable a vehicle crew commander to spatially input, organize and view fused tactical information through placement of 3D interactive symbols directly into the real-life on-site scene from the vehicle perspective. A panoramic camera, dashboard monitor and head tracker give the commander a complete view of the vehicle surroundings for improved situational awareness, and a 360-degree LiDAR scanner supplies depth information for accurate annotation geo-location. This system is intended to generate greater situational understanding of the complex environment present in COIN operations, in order to allow greater performance and survivability of the vehicle crew. Such a system, if fielded, can create the ability to add numerous other capabilities to the combat vehicle crew.

14. SUBJECT TERMS Augmented Reality, Panoramic Video; Indirect Vision; Situational Awareness; Knowledge Persistence; CROWS; Head Tracking;			**15. NUMBER OF PAGES** 127
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 8-98) Prescribed by ANSI Std. Z39.18

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PANORAMIC AUGMENTED REALITY FOR PERSISTENCE OF INFORMATION IN COUNTERINSURGENCY ENVIRONMENTS (PARPICE)

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**MASTER OF SCIENCE IN
MODELING, VIRTUAL ENVIRONMENTS AND SIMULATION (MOVES)**

from the

**NAVAL POSTGRADUATE SCHOOL
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LIST OF ACRONYMS AND ABBREVIATIONS

AA	Annotative Augmentation
AAR	After Action Review
AGC	Army Geospatial Center
AO	Area of Operations
AR	Augmented Reality
BFT	Blue Force Tracker
COIN	Counterinsurgency
COP	Common Operating Picture
CROWS	Common Remotely-Operated Weapons Station
DARPA	Defense Advanced Research Projects Agency
DOF	Degree of Freedom
EPLRS	Enhanced Position Location Reporting System
FBCB2	Force XXI Battle Command for Brigade and Below
FOV	Field of View
GIS	Geographic Information System
GPS	Global Positioning System
HMMWV	High-Mobility Multi-purpose Wheeled Vehicle
IED	Improvised Explosive Device
IFF	Identify Friend or Foe
KP	Knowledge Persistence problem
LIC	Low-Intensity Conflict
LiDAR	Light Detection And Ranging
MBT	Model-Based Tracking
MOOTW	Military Operations Other Than War
OST	Optical See-Through
PARPICE	Panoramic Augmented Reality for Persistence of Information in Counterinsurgency Environments
PARPICE-V	PARPICE Vehicle
PTZ	Pan-Tilt-Zoom

RWS	Remote Weapon Station
SimA	Simulative Augmentation
SINCGARS	Single Channel Ground and Airborne Radio System
TIGR	Tactical Ground Reporting
VBS2	Virtual Battlespace 2
VST	Video See-Through

ACKNOWLEDGMENTS

I would like to sincerely thank all the people who made this research possible.

First, for their generous monetary support, I would like to thank LTC Glenn Hodges, Mr. Gary Dahl, and all the other staff of the DA G8 / Center for Army Analysis Simulation Proponent Office, as well as the Joint IED Defeat Organization.

I would like to extend my most sincere gratitude to those at the MOVES Institute who advised me on my circuitous route through the curriculum, including CDR Joe Sullivan and the rest of the MOVES faculty.

I would like to thank my peers working in the NPS Vision Lab, especially Justin Jones, Jason Nelson, and my fellow traveler in the PARPICE-mobile: Rich Morrison.

For his valuable feedback; for making available the opportunity to get hands-on experience with relevant technologies; and for his time spent reviewing this monograph, I thank Dr. Mike McCauley. His expertise and advice proved quite valuable.

And for his relentless patience, enthusiasm for the topic, unlimited attention and invaluable mentorship, I would like to thank my advisor, Dr. Mathias Kölsch. I hope that, after much work, this manuscript measures up to what he always knew it could be.

But above all, I must thank my lovely, gracious wife, Liz, and our children, Thomas, Grace and Sophie. Your patience, encouragement, love and support were the only reason this document could come to be. I only hope I can give back to you the time you have so selflessly lent to me. I love you more than you will ever know.

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I. INTRODUCTION

Since the fall of the Soviet Union in the early 1990s, the United States military has found itself involved in conflicts that primarily fall on a lower position on the operational spectrum than conventional high-intensity combat. Names for these types of conflict change, but associated terms include Low Intensity Conflict (LIC), Counterinsurgency (COIN), and Military Operations Other Than War (MOOTW). Success in this type of modern combat is increasingly dependent on the flow of information. Compounding the difficulty of this situation are the circumstances found in a low-intensity combat situation, such as the counterinsurgency (COIN) we currently conduct in Afghanistan and Iraq. In this environment, the necessity to have situational understanding involving the civilian populace greatly increases the difficulty of operations, because social-cultural knowledge is difficult to describe and communicate. For example, it is useful to know if the house a user is looking at has been searched by previous units, and what was found during the search.

This thesis describes the design of a system incorporating Augmented Reality (AR) to make tactically-relevant information available to combat and patrol vehicle commanders in an operational setting. The focus of this research and prototype system development is to integrate spatially related data into an indirect view of the outside environment. Street names, building information, blue force platforms and intelligence data are fused with the video from vehicle-mounted cameras.

Figure 1 Unmodified view of urban Baghdad

Terrain-associated knowledge persists in the environment, rather than being verbally relayed, stored in text documents or on paper maps, or being lost entirely. Crucial information—unobtrusively displayed at the right moment and place—allows a vehicle crew to better understand their operational environment, to be aware of threats that may be present, and ultimately to improve situational awareness and crew safety. Generally, we wish to transform the view in Figure 1 into the view in Figure 2, and display

The following chapter explains the operational problems we are trying to address, as well as basic concepts of AR. Chapter III is a literature review, in which we present currently deployed systems and their capabilities and limitations. Chapter

IV is the analysis of the system requirements and prototype design. Chapter V describes our plans for future work. The last chapter summarizes our thesis and presents our conclusions.

Figure 2 Conceptual view through goal system

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II. BACKGROUND

A. OPERATIONAL PROBLEMS

1. Persistence of Knowledge and Understanding

In our current operational theaters, responsibility for a particular Area of Operations (AO) changes frequently, due either to scheduled deployment rotations or to unit moves within theater stemming from changes in operational requirements. This flux tends to create gaps in area knowledge for the responsible unit. Outgoing units have a good working knowledge of the area, providing the context within which to operate. Incoming units lack this knowledge and context. Units fresh to an AO interpret their surroundings differently than units that are veteran to the area. While the veteran unit is able to interpret environmental cues in a manner moderated by its experience, the new unit is lacking such nuanced information.

The current method of information exchange between rotating units generally involves two activities, which we will refer to as “ride-alongs” and “data dumps.” Ride-alongs involve the new unit leadership participating as observers as the outgoing unit conducts operations, thereby gaining exposure to the AO, and some verbal transfer of historical and situational knowledge. The “data dump” refers to the outgoing unit providing a massive amount of digital historical data in the form of slide shows, documents and images, saved on either hard disk drives or removable media such as CD-ROMs. This is usually an unsatisfactory method of information conveyance: the mere fact that the data is now in control of the incoming unit is very different from that unit’s understanding of the data and even more so from its being able to utilize the data. Furthermore, there also is a need for more accurate and precise tactical data collection in COIN operations, both for trend analysis and prediction as well as feedback on performance for operating small units.

The precision and accuracy of spatio-temporal data about events on the battlefield often are hampered by the necessity to rely on memories of individuals who witnessed the event. Anecdotal recollections tend to be inaccurate or falsely precise, and this limitation perpetuates throughout the information sharing structure, resulting in incorrect target location and inaccurate data collection. Since data analysis tends to be vulnerable to a ―garbage-in, garbage-out" phenomenon, improving the means of collection for more accurate and more precise data should have far-ranging implications.

In fact, very little information currently is collected in operational settings, and units do not have tools to review properties, timing and location of events. This is in contrast to training settings, where Observer/Controllers are viewing the unit's performance, and various automated instruments are available for tracking the elements of the unit, enabling playback and review of training events for after-action review (AAR). For instance, it is only on exceptionally rare occasions that actual IEDs are recorded in images prior to exploding, yet those are incredibly valuable for training and analysis purposes.

2. Constrained-View Situational Awareness

The view of the external world from within a tactical vehicle is limited due to the necessity of surrounding combat vehicles with armor to protect the occupants. For instance, an M1114 up-armored High Mobility Multipurpose Wheeled Vehicle (HMMWV) is surrounded by armor plating and armored glass. The armor helps protect the occupants, but results in very limited visibility. The crew in the front seats has best visibility through the forward 60-degree horizontal arc, with visibility more limited through the smaller side windows, and limited even further for the crew in the rear seats (see Figure 3). Because of the limited field of view, crew members in general and the vehicle commander in particular often rely on verbal information from other members of the crew to piece together a full picture of the surroundings.

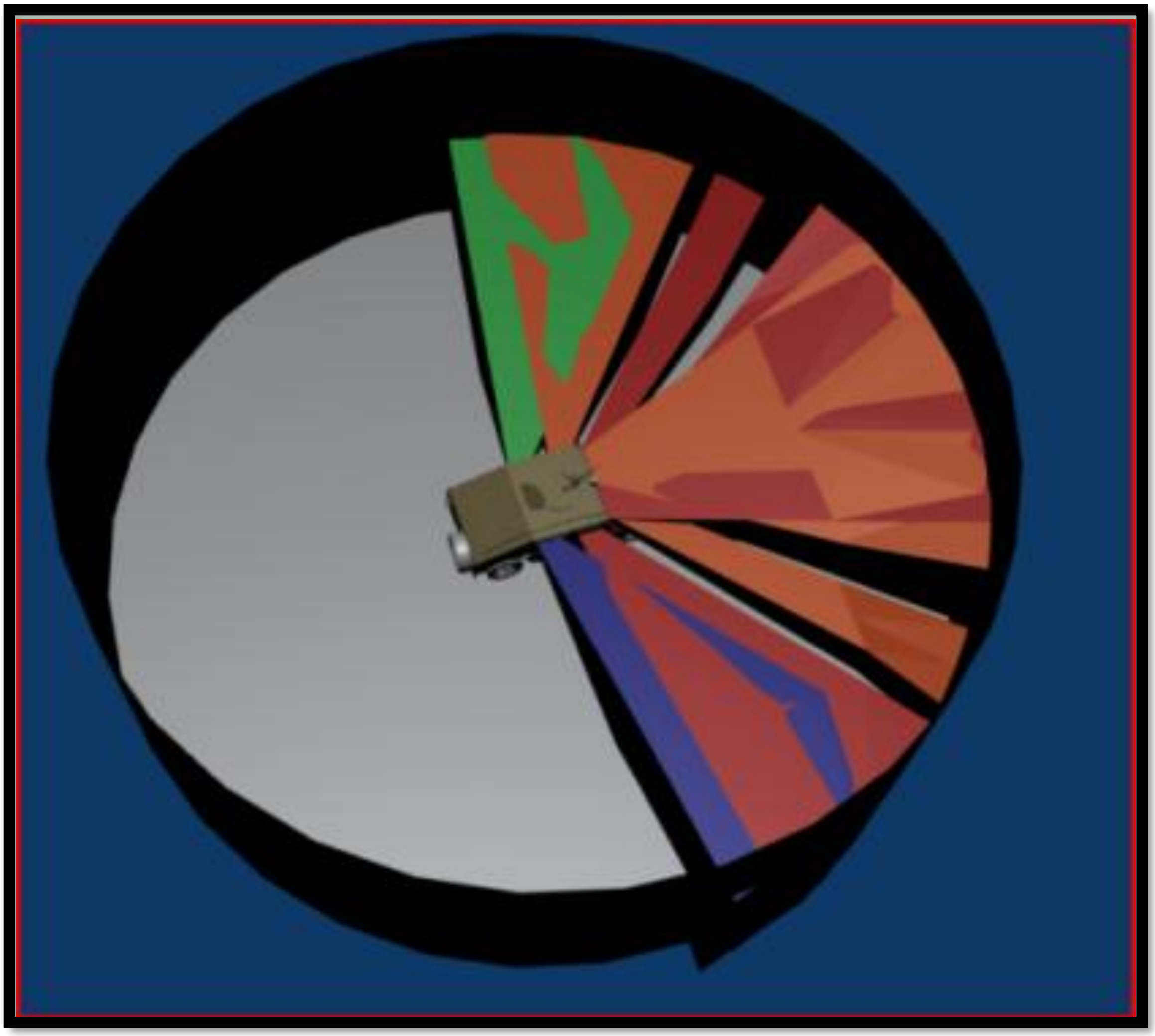

Figure 3 Crew fields of view from inside a HMMWV. Each color represents the field of view from a crew position. The mottled appearance is an artifact of depth-buffer fighting in areas where views overlap.

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III. CURRENT SOLUTIONS

The problems described in the first chapter—knowledge persistence and Constrained-View situational awareness—have existed throughout modern warfare, as can be seen by virtue of various attempts and several operational systems acquired in order to address them. In this section, we describe some previous solutions addressed at each problem, and both their benefits and drawbacks.

A. KNOWLEDGE PERSISTENCE

Throughout the history of warfare, there have been many ways of attempting to deal with the problem of providing a so-called Common Operating Picture (COP), which is consistent across the unit and common to all subordinate headquarters. The foundation of the COP rests principally on some sort of understandable representation of the terrain in the area of operations. On top of the terrain model, a structure is built out of components representing maneuver elements, area boundaries, target locations and other pertinent data. This COP is then regularly disseminated and updated with the current picture, which constantly changes over time. So far, there have been various, increasingly capable methods for distributing, viewing, saving and/or organizing this tactical knowledge.

1. Paper Map Overlays

Perhaps the simplest way of conveying the operational picture is a sketch depicting the AO and graphic control measures. Until recently, this basic method was the only way to track the tactical scene. The practice of using military maps typically involves a base topographic map with terrain features, with transparent overlays laid on top, aligned via “witness marks.” These overlays have tactical graphic control measures drawn on them, usually in an indicative color. Boundary overlays are drawn using black; obstacle overlays are usually green; enemy locations are red and so on. These overlays can then be placed on the map in various combinations based on the user’s needs.

Another variation of paper maps is the creation of printouts of digital products, such as PowerPoint™ slides. These slide printouts have recently been the major way of getting portable information to low-level units, because current command and control systems in vehicles do not provide the desired information fusion.

Advantages

- Persistent: requires no power source
- Portable: can be folded and stuck in pockets

Drawbacks

- Low fidelity and detail: restricted to one scale
- Comprehensive maps are physically large and ungainly
- Immutability: maps cannot be updated in a standardized way
- Overlays must be carefully managed, due to outdating

2. Sand Table

A sand table is a venerable standard format for conducting rehearsals, which in turn provide a common framework from which to operate. A portion of ground (preferably sand) is sectioned off, and a miniature terrain model is built of the operational plan. (Sometimes an actual table with walls, filled with sand is used, but this is mostly in school environments.) Roads, rivers, hills, other terrain features and inhabited areas can all be portrayed with common school supplies, and operational information can be written on cards and placed around the model. Subordinate units are depicted as well, and at the very least the unit key leaders gather around the model (or actually stand inside it) and walk through the operation in miniature (Figure 4). This rehearsal method is a good way to ensure synchronization among subordinates. Map rehearsals are similar to sand tables, differing mainly in that a map is used instead of a dirt model, and consequently the number of participants is limited

Figure 4 Sand table (From [1])

Advantages

- Relatively simple
- Minimum infrastructure required
- General familiarity across the force

Drawbacks

- Can be time-intensive to construct
- Generally more of an abstraction than realistic model
- Requires collocation of rehearsal participants

3. Blue Force Tracking Systems

Blue Force tracking systems are the recently fielded digital command and control systems for use in vehicles and other battlefield entities. At their most basic, they allow position information of individual vehicles to be shared across the force, creating a common picture of the locations of friendly forces. Their

elements usually include a vehicle or soldier-mounted processing device and flat-panel display, and a wireless network (usually either a satellite broadcast network, or a peer-to-peer mesh network), and some less mobile network control nodes Other features can be added to take advantage of the capability provided by the network.

a. FBCB2/BFT

Force XXI Battle Command for Brigade and Below (FBCB2) [2] and Blue Force Tracker (BFT) are the digital communications platforms currently in use in the majority of U.S. combat vehicles. These two systems both consist of hardened/rugged digital computers mounted in vehicles (Figure 5) and connected to GPS receivers and wireless communication. They differ mainly in that FBCB2 achieves connectivity to the tactical network through either the Enhanced Position Location Reporting System (EPLRS) digital radio transceiver (which is specifically dedicated to digital connectivity) or the Single Channel Ground and Airborne Radio System (SINGCARS) standard radio (also used for voice communications), while the BFT connects to the network through a satellite transceiver.

Figure 5 FBCB2 hardware mounted in a HMMWV (From [3])

These two systems are used for multiple purposes, which are centered on the concepts of:

- Self-position location via GPS
- Tracking and display of the locations of other units with similar systems, through a tactical network through which each element reports and updates its own position on a periodic basis
- An top-down view display to depict locations and properties of all the connected blue force elements, aligned with topographical map data and/or aerial imagery (Figure 6)
- An overlay system whereby tactical mission graphic control measures can be overlaid on the topographic data to depict boundaries, routes and other information

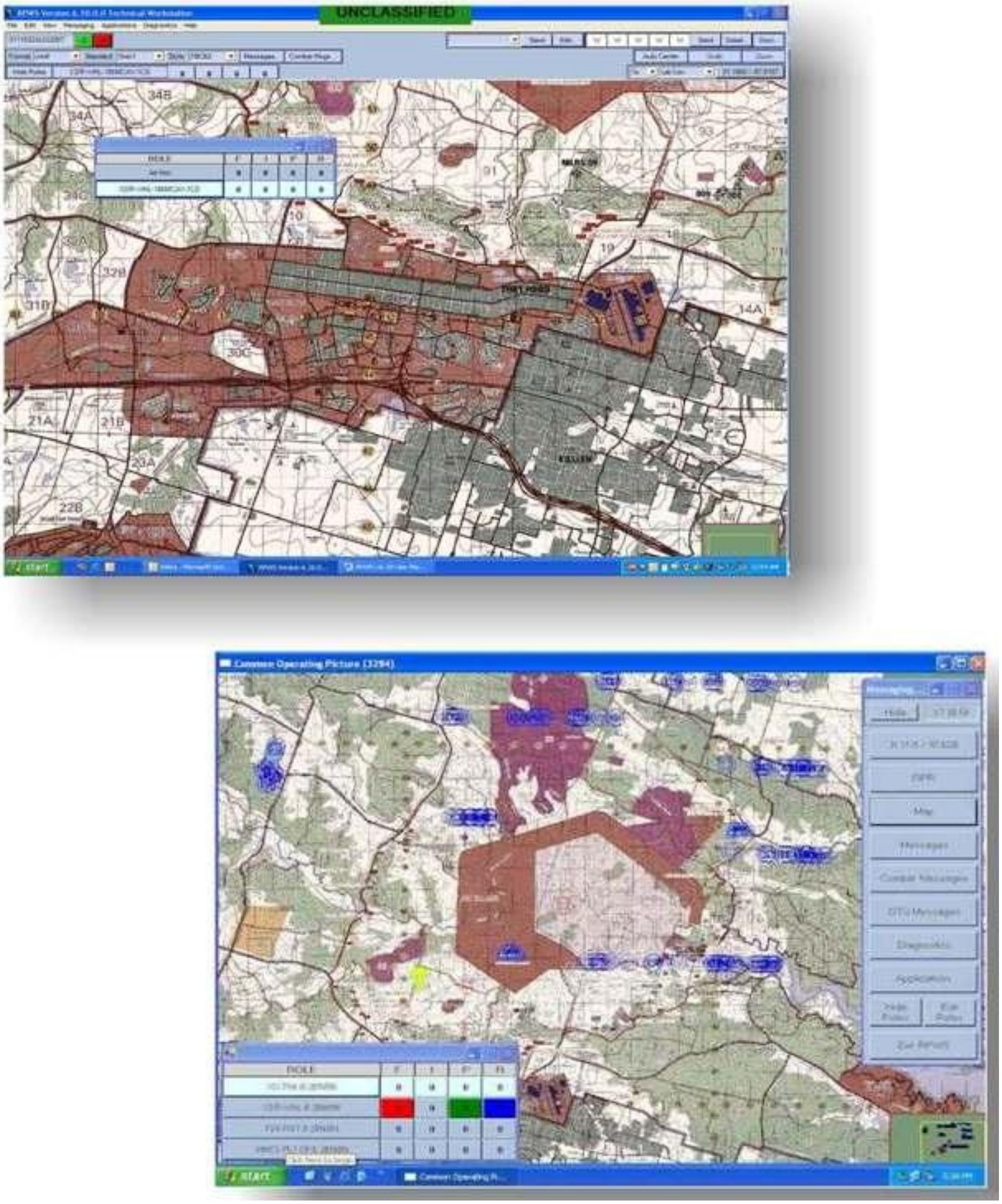


Figure 6 FBCB2 display (From [4])

- A tactical messaging system for sending various text reports to either one or multiple elements, as well as disseminating graphics overlays which can then be displayed

FBCB2 functional capabilities can be seen in Figure 7 [5].

Area	FBCB2 Capabilities
Digital Basics	Establish proper communication network
	Clear queues and logs
	Set filters and respond to alerts
	Use filing/naming conventions
	Perform maintenance and troubleshooting
Battlefield Visualization	Relate threat to own/unit location
	Tailor situational awareness (SA) picture
	Manage Red icons
	Post obstacle overlays
Mission Planning & Preparation	Apply Line of Sight (LOS) tool for terrain analysis
	Apply LOS tool for perimeter defense planning
	Use FBCB2 to plan and control fire support
	Use FBCB2 to support logistical planning/preparation
	Construct and update overlays
	Leverage FBCB2 in multi-echelon wargaming
Information Exchange	Prepare and manage messages and graphics
	Disseminate messages and graphics
	Confirm reception of critical messages
Mobility & Maneuver	Use FBCB2 to plan and execute movements
	Leverage FBCB2 in maneuver decisions
	Exploit FBCB2 in fratricide prevention

Figure 7 Table of FBCB2 functional capabilities (From [5])

Advantages

- The first widely used digital blue force tracking system, in pervasive use among all U.S. forces
- Allows the user to understand much more of the tactical situation than was previously available
- Part of the Army Battle Command System suite of systems, which allows lower-level tactical information to be integrated into the higher level Common Operating Picture (COP)

Drawbacks

- Positioning of blue forces is not real-time: it is periodic, because updates are sent using a —heart beat" method to allow all positions to update on the network. Additionally, in practice, the GPS does not provide exceptional accuracy.
- From an operator's perspective, the system has an interface that meets all specified requirements, but is awkward for active use in combat situations
- Originally intended to provide information dominance on a high-intensity combat battlefield: suitable for maneuver warfare, but lacks fidelity or versatility for urban COIN operations.

b. Tacticomp

Tacticomp™ (see Figure 8) is a system produced by Sierra Nevada Corporation [6] that combines many functions provided by FBCB2, as well as other functions such as video streaming capability and file sharing. It has been test-fielded to some units in theatre, but has not been acquired on a large scale.

Advantages

- Provides many of the same functions as FBCB2
- Allows flexible interface for users to share more ambiguous data, such as on-the-fly sketches and images
- Runs on the Windows operating system, which greatly reduces the learning curve for soldiers already familiar with such systems
- Dismountable

Figure 8 Tacticomp 6 tablet (From [6])

Drawbacks

- Not fielded in large numbers, so the mesh network involved is not very robust
- Also limited to 2D depictions of the battlespace

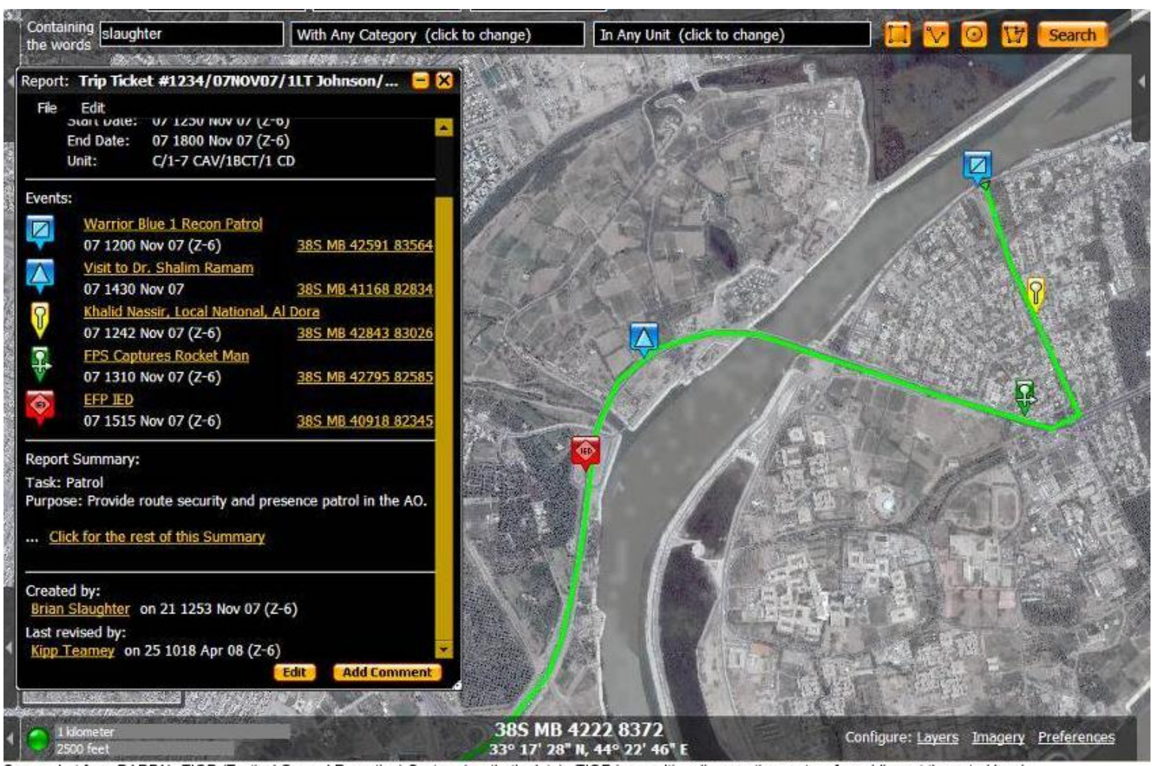
4. Web-Based Tactical Information Assets

With the proliferation of computing and networking technology, the basic Web browser can be used as a device for a shared operational picture. Numerous databases of tactical information can be connected via server-side software, and accessed on the network by dispersed users using Web page interfaces. These information sources can be scaled well, and can be updated as necessary on the server side, rather than requiring hardware or client software updates. These online repositories can provide a much greater depth and breadth of information to the user, as opposed to the currently fielded mobile

systems. However, they also consume bandwidth that might not be feasible over current tactical networks.

a. TiGRnet

The Tactical Ground Reporting system (TiGRnet) [7] is a program spawned from DARPA that found great success in current operations. It is essentially a GIS Web service (see Figure 9), which allows small tactical units to compile, spatially relate and share numerous types of relevant information in a dispersed manner. The system involves a server architecture that allows units to establish their own local system that is simultaneously connected to the rest of the TiGR network.



Screenshot from DARPA's TIGR (Tactical Ground Reporting) System (synthetic data). TIGR is a multimedia reporting system for soldiers at the patrol level, allowing users to collect and share information to improve situational awareness and to facilitate collaboration and information analysis among junior officers. DARPA Image.

Figure 9 TIGR large-scale view (From [8])

The core TIGR service involves a map interface, which incorporates the capability to access many layers of information. Units can upload pictures,

video and documents, and associate them spatially with particular locations and/or individuals. Units can do a walkthrough of routes they are planning to take, or locations where they intend to operate, and access any pertinent information about locations and sites that they may pass or transit. This allows much greater contextual understanding of the upcoming mission environment, and the data can also be integrated with other systems for intelligence analysis.

Advantages

- Allows integration and sharing of numerous forms of pertinent information
- Web service model allows for easier configuration management
- Allows spatial contextualization of information

Drawbacks

- Not currently mobile: units do not have access during operations, but only back at a fixed site with connectivity, thus limiting use to pre- and post-operation periods.
- 2-D map based on aerial imagery does not permit distinction of height-off-the-ground as might be of importance to ground-based forces. This limits fidelity, immersion and presence

b. Buckeye

Buckeye is the name of a product from the Army Geospatial Center (AGC) [9] that provides high-resolution overhead imagery of numerous locations throughout the theater of operations. These images are commonly placed into PowerPoint slides, and have operational graphics drawn upon them. These images provide a greatly increased sense of the area being viewed, compared to standard topographical maps.

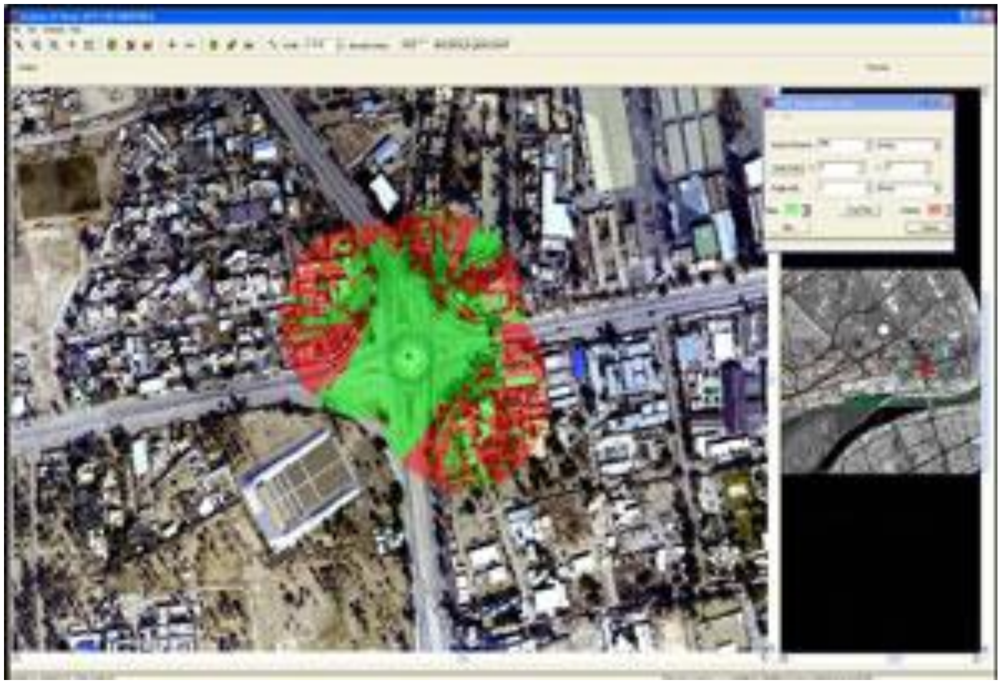


Figure 10   Buckeye View (After [10])

Advantages

- High-resolution aerial imagery
- Simple interface

Drawbacks

- Images sometimes taken at oblique angles
- Limited or no detail of vertical surfaces

c. Project Tourist

Project Tourist [11] is another AGC service that incorporates spherical video of urban areas synced to a top-down map view that allows the user to select routes to view. These routes can then be viewed as a virtual tour, with the map showing the top-down location, and the video or panoramic still frame showing the surroundings at that point. This service is very similar to Google StreetView™ [12], but provides data of areas in the active theater of operations.

Advantages

- High-Resolution Street-level panoramic imagery and video
- Provides multiple angle views of street-level features

Drawbacks

- Collecting capability not yet distributed
- Data can be out of date
- Currently no depth data on the video, limiting the geo-spatial correspondence between the spherical view and the top-down map
- Opportunities for confusion

d. SharePoint™ and Web Portals

A common method for documenting and storing tactical knowledge is by using office software (usually Microsoft Office™) to generate documents, which are then saved on the tactical network. These products can span all the way from text-only documents to complex multimedia presentations. Once they are constructed, these documents can be shared for collaboration purposes via Web portals on the tactical internet.

Advantages

- Allows detailed documentation
- Existing familiarity across the force

Drawbacks

- Currently must be printed out to be taken on operations
- File size becomes quite large with added detail: long transmission lag

5. Serious Games

Figure 11 U.S. Army cadets participating in game-based training (From [13])

Some units, on their own, have made inroads into the use of commercial first-person simulation games (such as ArmA 2 [14]) for rehearsal purposes. The U.S. Army and USMC have recently adopted a similar system, Virtual Battlespace 2 [15] as an official gaming platform. This can be an effective means of rehearsing an operation.

Advantages:

- Allows visualization of the actual mission
- If networked, allows a much more realistic rehearsal than other methods, and thus better cognitive absorption of the operational environment.

Drawbacks

- Requires digital terrain, which may be time-consuming to build
- Requires hardware and software for each participant, which is not usually available
- Not currently configured to generate game objects from battle command system data

6. Analysis

The identified approaches to addressing the Knowledge Persistence problem can be analyzed and relative strengths and weaknesses compared, in order to develop a more satisfactory solution. For each current solution, we have assessed the relative strength of four characteristics appropriate to the domain.

a. Terrain View

This attribute is a rating of the ability of the solution to provide a detailed, realistic view of the terrain in the operational environment in question, in which contextual information can be situated.

b. Available On-the-Move

This attribute is a rating of the ability for the solution to be utilized while in the operational environment, in a moving vehicle.

c. Data Updatability

This attribute rates the ease with which the system can update, change and disseminate new information.

d. Placement of Spatial-Contextual Information

This attribute is a rating of the degree to which the solution provides the ability to view information in its spatial/situational context, in order to enhance the user's understanding.

For each of these described attributes, we have assessed each identified solution on a scale from 1 to 5 , with 1 being —very strong” and 5 being —very weak,” as displayed in Table 1 .

Table 1 Solution assessment–Knowledge persistence

Problem: Knowledge Persistence	**Assessment**			
Solutions	Terrain View	Available On-The-Move	Data Updatability	Spatial-Contextual Info Placement
Paper Maps w/ Overlays	4	2	5	4
Sand Table	3	5	4	4
Blue Force Tracking Systems	3	1	3	4
Web-Based Tactical Information Assets	3	5	2	3
Serious Games	2	5	4	3

Upon reviewing our subjective assessments, one can see that none of the solutions is particularly effective across all attributes, and none have more than one attribute scored above —3,” or —fair.” Since it is our intent to solve the Knowledge Persistence problem in a more satisfactory manner, it is important that our developed solution show improvement across our identified attributes.

B. CONSTRAINED-VIEW SITUATIONAL AWARENESS

Aside from maintaining a COP and persisting the knowledge it contains, operating forces must be acutely aware of their immediate surroundings and observe and process the environment and situation. This ability to generate situational awareness becomes problematic through the restriction of view of vehicle crewmembers due to necessary armor requirements.

1. Human Gunner-Observer

To alleviate the visibility problem, most combat vehicles employ a gunner in a turret position atop the vehicle, to perform two tasks: engage targets with a direct-fire weapon, and provide visibility around the vehicle. The latter task is much more prevalent than the former. Because of this need to see, gunners must have visibility, which conflicts with survivability: gunners are by far the most vulnerable member of vehicle crews. Their position makes them vulnerable to small arms fire and IED explosions. Additionally, because of the unwieldy nature and high center of gravity of heavily armored wheeled combat vehicles, rollovers are relatively common, and gunners are very vulnerable in such situations.

HMMWV gunners (see Figure 12) historically have had a high casualty rate in combat. Because of this, there has been a focused effort made to mitigate this vulnerability: first with turret armor, and then armored glass was added to turrets to protect against small arms and fragments. Also, gunners have been given harnesses and tie-downs in order to prevent them from being thrown from the vehicle during rollovers. The Army has gone so far as to develop an armored suit for gunners to wear, similar to the ―bomb suits" worn by explosive ordnance technicians (see Figure 13 [16]).

Figure 12 A gunner in a HMMWV turret

Advantages

- Gunners have a far better field of view than crew in the vehicle
- They can engage targets with either lethal or non-lethal weapons as appropriate
- Gunners provide the advantage of being able to communicate with the local civilian traffic via hand and arm gestures in order to convey intent and commands: this helps prevent misunderstandings and escalation of force incidents

Drawbacks

- Gunners are vulnerable to small arms fire
- Gunners have less protection from explosions than the rest of the crew
- Gunners get thrown from vehicles, pinned and/or crushed

- Measures necessary to improve survivability for gunners result in degradation of other vehicle characteristics: vehicles develop a higher center of gravity, and unwieldy protective apparel and safety measures create difficult conditions for gunners. [18]

Figure 13 Cupola Protective Ensemble (CPE) for gunners (From [17])

2. Remote Weapon Stations

Recently, remote weapons stations (ex. Figure 14) [18] have become more prevalent and widespread. These systems are essentially a remote-controlled weapon mounted atop a vehicle that can be aimed and fired by an operator inside the

vehicle, viewing the target through electro-optics. These are in use on almost every one of the Stryker combat vehicle variants; are being mounted on HMMWVs and MRAPs; and are even being incorporated into the Tank Urban Survival Kit, an add-on kit for the M1A2 Abrams tank. These allow the gunner to stay inside the relative protection of the vehicle while being able to engage targets with high precision.

Figure 14 XM-153 CROWS remote weapon station (From [19])

Figure 15 USAF airman demonstrating the CROWS weapon control station inside a HMMWV (From [20])

Advantages

- Better protection for the gunner
- Enhancing imaging capabilities, including thermal optics
- Much more precise target engagement and stabilization method

Drawbacks

- Mechanical malfunctions more common
- Gunner has limited FOV at any one time (“Soda Straw” effect)
- Vehicle Commander does not have override or view capability

3. See-Through Turret

The U.S. Army has experimented in the recent past with the concept of the –See-Through Turret.” The system involves mounting cameras around the outside of a tank or other combat vehicle, with interior displays for the crew members to view the entire surroundings of the vehicle, with no or few blind spots [21] This has not progressed past the prototype stage, although the CROWS program management has expressed interest.

Advantages

- Crewmembers can view the entire surroundings of the vehicle simultaneously, improving SA

Drawbacks

- Display methods have been troublesome: HMDs and flat displays have been tried, but with difficulties
- Crewmembers are often busy with other tasks (loading the main gun, driving, engaging targets) which makes additional information difficult to handle

4. Analysis

As in the Knowledge Persistence (K P) problem, these identified approaches to addressing the Constrained View Situational Awareness problem can be analyzed, and relative strengths and weaknesses again compared. In this case, for each current solution, we have assessed the relative strength of four attributes:

a. Crew Protection

This attribute is a rating of the additional protection added to the vehicle crew by the application of the rated solution.

b. Vehicle Commander Visibility

This is a rating of the overall visibility of the surrounding environment provided by the system to the vehicle commander using the system, which is critical to the SA of the crew in general.

c. Weapon System Integration

This attribute rates the degree to which the vehicle's weapon systems are integrated with the situational awareness solution (that is, the ease with which the crew can identify and engage a valid target).

d. Placement of Spatial-Contextual Information

As in the K P problem, this attribute is a rating of the degree to which the solution provides the ability to view information in its spatial/situational context, in order to enhance the user's understanding.

Again, for each of these described attributes, we have assessed each identified solution on a scale from one to five, with 1 being —very strong" and 5 being —very weak," as displayed in Table 2 .

Table 2 Solution assessment–Constrained view situational awareness

Problem: Knowledge Persistence	**Assessment**				
Solutions	Terrain View	Available On-The-Move	Update Frequency	Spatial-Contextual Info Placement	GIG Integration
Paper Maps w/ Overlays	4	2	5	4	5
Sand Table	3	5	4	4	5
Blue Force Tracking Systems	3	1	2	4	3
Web-Based Tactical Information Assets	3	5	2	3	1

Similarly to the previous problem, upon reviewing our subjective assessments, one can see that none of the solutions is particularly effective across all attributes, and high scores in some attributes tend to be balanced by poor scores in other attributes. Since it is our intent to also solve the Constrained View Situational Awareness problem in a more satisfactory manner, it is important that our developed solution shows improvement across our identified attributes.

Some desirable improvements to the current status-quo will be addressed in our prototype system, some of which include:

- 360-degree visibility for TC (and perhaps others)
- Precise weapon fire control by vehicle commander
- Nonobstructive/obtrusive

IV. SOLUTION DEVELOPMENT

In our search for better solutions to the two identified operational problems of Knowledge Persistence and Constrained-View Situational Awareness, we propose that a technical development known as Augmented Reality (AR) has the potential to address both problems simultaneously in one combined solution. Prior to discussing our findings on this topic, we must first provide a background overview of this technology to be investigated.

A. AUGMENTED REALITY

Augmented Reality [22] is the imposition of spatially-registered computer graphics over a live image of the real world, be it a video feed (known as video see-through AR) or a direct view (known as optical see-through AR). The essential characteristic of AR is spatial registration: simply imposing text or other iconography over the live image does not make a system qualify as augmented reality. By spatial registration, we mean that the augmentations move with the view: that is, the generated graphics behave visually as if they were located at an actual point in space. Augmented reality is a part of a so-called –reality/virtuality continuum” [23], as seen in Figure 16 , with –actual” reality on the left, and fully simulated or virtual reality on the right.

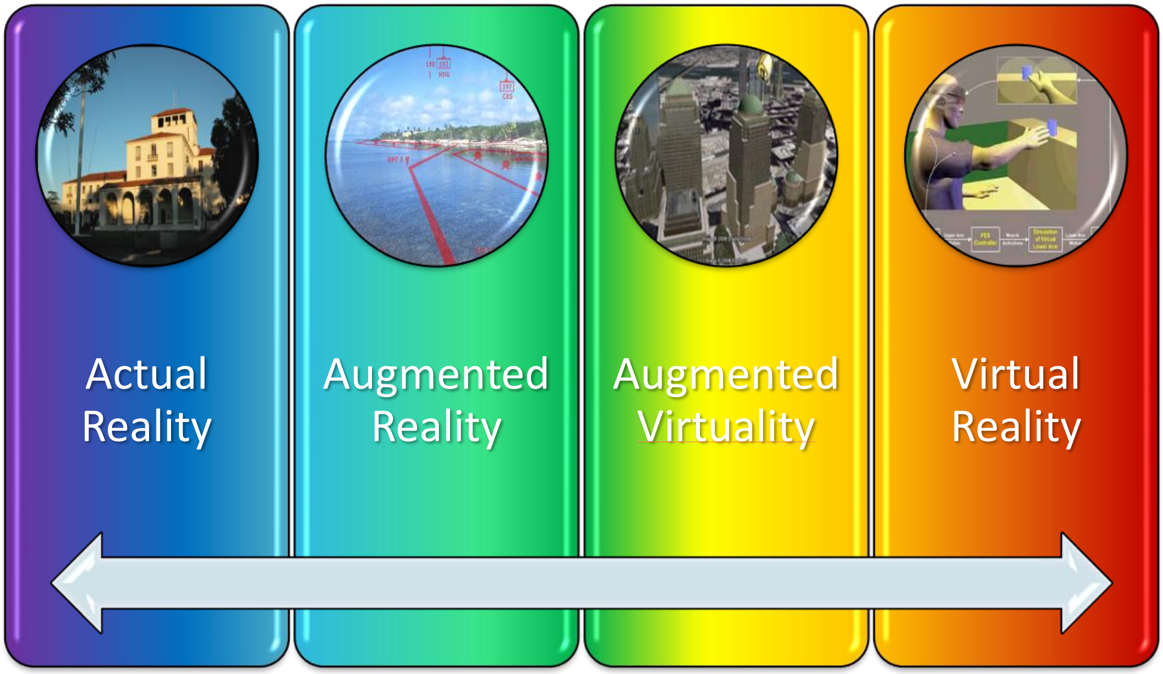


Figure 16 Milgram's Virtuality Continuum

B. AR REQUIRED CAPABILITIES

1. Determine Pose of Point of View

In order to effectively augment reality (as well as to provide several other desired capabilities), we must determine both the location and orientation (or pose) of the viewer, in order to register the generated augmentations with the physical world. Registration is critical in AR: registration error causes a cascade of problems, including erroneous icon placement, movement of annotations, and general inaccuracy of data. For this reason, we must seek to register the user point of view as accurately and precisely as possible. This requirement can be addressed in various ways.

a. Degrees of Freedom

When discussing registration, the key concept involved is degrees of freedom (DOF). A degree of freedom (in mechanics) is a displacement or rotation of a body or physical system: DOFs of a body are the set of these that specify

completely the displaced position and orientation of a body. This can be generalized as: a rigid body in d dimensions has $\frac{d(d+1)}{2}$ degrees of freedom (d translations and $\frac{d(d-1)}{2}$ rotations). The 3-dimensional space we inhabit is 6 DOF: 3 degrees of translation, and 3 of rotation.

(1) Position. The easiest way to describe translations is in Cartesian coordinates: [X,Y,Z], where X, Y and Z are axes with one degree of freedom each, and are orthogonal to each other. However, this only applies at local scales. If we are describing coordinates in a global sense, we will come upon a problem: that the Earth is round. If we start at a point on the equator, and move 90 degrees of longitude to the west, around the globe, “down,” which previously was a distance in the –Z direction, is now actually a distance in the previous X direction. This fact comes into play when we are describing things on a geographic scale, and because of it, the coordinate system commonly used in georegistration uses the measurements known as longitude, latitude, and altitude. These are spherical coordinates, with longitude being measured in degrees of rotation around the earth’s axis, latitude being measured in degrees of rotation from the equator toward one of the Earth’s poles; and altitude, which is commonly measured in feet or meters above (or below) sea level. Altitude is not as simple as lat-long, because the distance from the center of the earth to a standard sea level varies dependent on where you are located: the Earth is not a perfect sphere, but instead resembles an ellipsoid. A base reference model of this imperfection is known as a datum, or standardized model, which is then normalized as sea level, or zero altitude. The conventional global standard for navigation is known as the World Geodetic System 1984, or WGS 84. This is the datum used in the Global Positioning System (GPS).

(2) Tracking. For tracking in AR, we must keep the Cartesian/Geographic coordinate distinction in mind, and must be able to convert between the two. Orientation is commonly expressed as degrees of rotation (three,

in our case). These degrees are usually expressed as Euler angles, which are rotations about each of the three translational axes. A specific type of Euler angles, known as Tait-Bryan angles, are known by aviators as —Yaw, Pitch and Roll": these each indicate a body's rotation around its own Z, Y and X axes, respectively.

Orientations are also subject to frames of reference, whether we are referring to global or local rotations. In the case of AR, orientation is usually taken to mean rotation about the axes of latitude, longitude, and altitude, with respect to the geographic datum.

(3) Pose. Pose is a term indicating the combination of translation and orientation, to form a representation of all six degrees of freedom of an object.

b. Types of Tracking and Registration

Tracking and registration are two sides of the same coin. Tracking is the process of identifying the pose of external objects, based on the knowledge of one's own position, while registration can be looked at as determining one's own position, based on external stimuli. There are various ways of accomplishing both, as follows.

(1) Fiducial Marker Tracking. In this method, a camera is used that captures a video stream of the real world. Fiducial markers (such as seen in Figure 17) are then placed in the environment, and their pose is determined using computer vision techniques.

Figure 17   Example of a fiducial marker

When a marker is seen by the camera, computer vision techniques are used to recognize the marker, which then allows augmentations to be placed relative to the marker’s position. There are numerous software libraries available to implement this method: ARToolkit [24], ARTag [25] and StudierStube [26] are perhaps the most popular.

Degrees of Freedom: This method allows full 6DOF calculations, as long as the markings are visible to the camera: accuracy increases with an increase in size of the marker or decreased distance to the marker, because either of these conditions effectively increases the resolution of the marker to the camera.

Advantages: One feature that could find military application is to place markers on vehicles as both an Identify Friend or Foe (IFF) aid and a ~~b~~arcode hyperlink,” which would allow the vehicle to be identified by the system and be tracked automatically, as long as it remained in sight.

Limitations: While this method is suitable for many AR applications, military uses are limited because the markers must be preplaced: this requirement makes annotation of a large urban environment difficult.

(2) Markerless Vision Tracking. The Markerless Vision Tracking method also uses a camera, but no markers are placed. Computer vision methods are used to locate natural features, and calculate the camera's position based on optical flow and other characteristics. This method has the benefit of not requiring markers, but is computationally intensive. There are several ways to implement markerless tracking: some include using models of the surroundings, which simplifies the task. Others use techniques to generate a model from the video itself. ARToolkit Natural Feature Tracking [27] is one library that attempts to implement pose estimation without the use of markers prepositioned in the environment.

Degrees of Freedom: The Markerless Vision Tracking method can also determine all 6DOF.

Advantages: Visual feature tracking has the advantage of not requiring pre-annotation or markup prior to use: these systems can be easily used in new environments.

Limitations: Natural feature tracking is computationally intensive. Also, it is susceptible to changes in the lighting environment, such as changes in contrast or brightness.

(3) Model-Based Tracking. Model-based tracking (MBT) [28], [29] is related to natural feature tracking, in that features in video are also tracked. However, in this case, we create a 3D model of the environment beforehand. We can render the model, and compare it to the video. Given a particular image from the video, a most-probable self-location can be calculated by determining the spot where the model and video are most similar.

MBT obviously requires that we construct the model beforehand. The model could be constructed manually, using 3D modeling

software, or automatically, if we could automatically capture the texture and structure of an urban environment and transform it into a model

Degrees of Freedom: We can track in 6DOF using the model-based tracking method.

Advantages: The model-based tracking method combines some of the advantages of both marker and markerless tracking: like marker-based tracking, it has the advantage of prior knowledge of dimensions of features being tracked. Also, like natural feature tracking, it does not require any actual external infrastructure (this having been replaced by the model)

Limitations: MBT requires an accurate model for good performance: an inaccurate model has adverse effects on positioning, because the probabilities are reduced. Urban terrain changes with time, so the model must be updated frequently. And, construction of a model is nontrivial.

(4) Inertial Tracking. In this method, various sensors (to include accelerometers and gyroscopes) are used to detect changes in orientation and translation, by integrating the acceleration over time. These techniques have the benefit of not depending on any external signal, other than gravity and inertia. They have the disadvantage, however, of drifting over time; this drifting requires additional tracking means to recalibrate the inertial sensor.

Compasses are similar to inertial trackers, in that they measure the direction of an acceleration (in this case a force caused by the Earth's magnetic field), which presumably aligns north-south.

Degrees of Freedom: Inertial sensors are limited by the physical properties of the type of sensor used. Most are meant to sense

orientation: gyroscopes, for example. Others sense acceleration, both rotational and translational: if we integrate twice over the accelerations, we can get changes in pose, for a full 6DOF.

Advantages: Inertial sensors require no external signal, so they can be used in almost any environment.

Limitations: These sensors are limited by several factors, primarily vibration and drift. Vibration introduces noise into the system, which can skew measurements. And most inertial sensors drift over time, so that their internal reference coordinates differ from those of the real world. Because of this, inertial sensors tend to be combined with other methods, in order to "recalibrate" these reference coordinates periodically.

In the case of a compass, magnetic fields can be generated by things other than the Earth, and magnetic objects can skew the instrument.

(5) External Signal Tracking. External Signal Tracking (EST) involves reception of external signals that provide pose information. One example is the Global Positioning System (GPS): the constellation of GPS satellites orbiting the Earth send out very precise timing signals. Because we know the location of the satellites, we can compare our local time with the time encoded in the transmission from each satellite. From these timing differences, we can calculate the intersection of all the spheres centered at each satellite, with a radius equal to the speed of light multiplied by the timing difference to that satellite. That intersection point is our current location.

The case of GPS is different from other tracking methods: its primary purpose is to measure translation, and pure GPS does not measure orientation. However, this limitation can be remedied by making some assumptions: mainly, that a vehicle tends to point in the direction of its own movement. For land vehicles, this usually is a reasonable assumption. If we make

this assumption, then we can track GPS points over time, and use the orientation of the vector between the points as the orientation of the vehicle. However, this technique is restricted to estimating pitch and yaw. Any degree of roll could be valid, because we are assuming we are moving along the X axis.

Advantages: GPS tracking is available for most places on Earth, and it does not require any prior knowledge of the environment. It can also be highly precise, if additional technologies such as Differential GPS are used.

Limitations: Since GPS relies on electromagnetic (radio) transmissions, it can be susceptible to interference, and it suffers the aforementioned limitations to measuring mainly translation.

(6) Hybrid Methods. As mentioned, all of the common tracking methods suffer from one or more limitations. However, they can be combined in various ways to greatly improve performance. For instance, several applications have been developed for the Apple iPhone® 3GS that implement AR-type capabilities. These applications combine the native sensors on the phone (GPS, gravitational accelerometer, and compass) with video tracking using the phone's camera to provide registration. Google's Android™ phone operating system also has multiple applications in a similar vein. These are simple applications, on small mobile devices, but demonstrate great potential for the fusion of sensor data.

In a larger format, there are several INS products available that remedy the noted limitations of inertial sensors by updating the system with GPS data, in order to avoid drift issues.

2. Display View

A second component of Augmented Reality is the view of the world, which has annotations inserted into it. Since AR must combine the real world with generated

images, there is a complex set of characteristics in the interplay between the technical system and the human user that determines whether or not displays are suitable for tactical use.

a. *Characteristics of the Human Eye*

In order to evaluate the characteristics of displays, let us consider some anatomical and functional characteristics of the human eye. The human eye has resolution characteristics as shown in Table 3 [30]:

Table 3 Visual resolution characteristics of the human eye

Characteristic	High	Low
degrees/pixel	0.02	0.03
pixels/degree	50	33
num pixels/360°	18,000	12,000
radius (radial pixels)	2,864	1,909
Area (square pixels)/ Visual sphere	105,246,320	45,795,386
Area (megapixels)/ Visual sphere	105	46

As Figure 18 illustrates, these metrics indicate a “pixel size” for the eye is approximately 1.2–1.8 arc-minutes or 0.02–0.03 degrees.

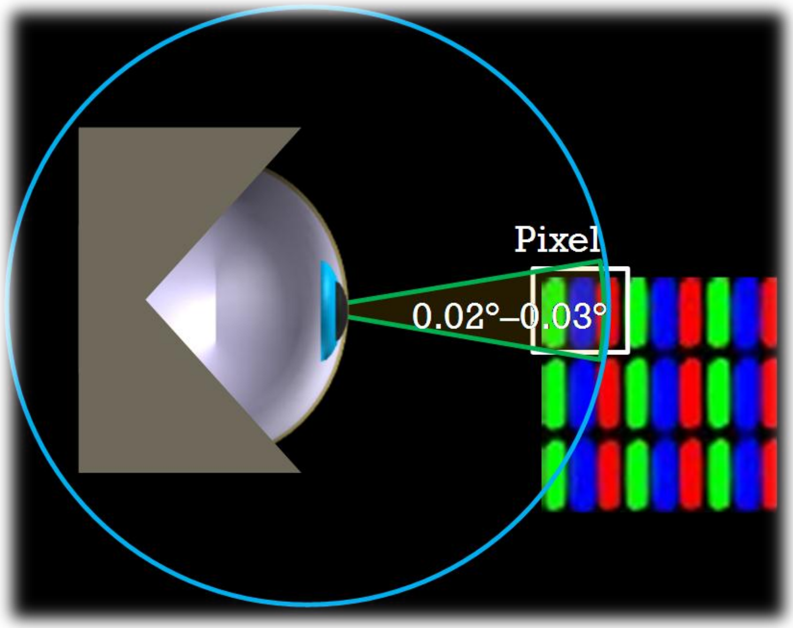


Figure 18   Human eye resolution

From these rough measurements, we can see that the order of magnitude of the area of the visual field of a human, in terms of square resolution units, is near 10^8 square “pixels.” This is not actually a very accurate figure, since it approximates taking one’s eyes and scanning the fovea of the eye over every patch of an imaginary sphere centered at one’s head, but it gives a rough order of magnitude. To get an idea this resolution, one might surround oneself with 10 WXGA+ LCD monitors edge-to-edge in a circle (10 times 1440 horizontal resolution).

That rough order of magnitude is for an entire sphere: humans do not see in a panoramic fashion. Figure 19 [20] shows the typical overlapping binocular field of view for an average person. The center of the diagram indicates the center of the composited field of view for both eyes: the concentric circles indicate the angular displacement from that center, from 0–90 degrees off-center, in all directions. The radial lines indicate the direction of the angular displacement. The white region indicates overlapping field of view with both eyes, while the

hatched region indicates the regions that can be seen with one eye only. The black indicates regions outside the FOV. (These regions are asymmetric due to a margin of error in the data.)

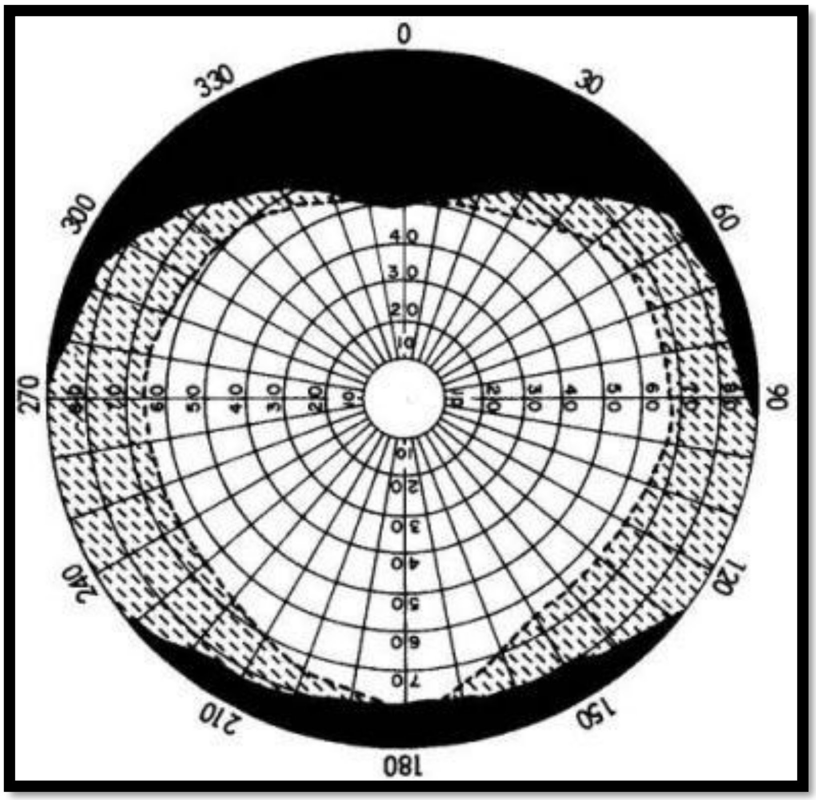


Figure 19 Human field of view (From [31])

Figure 20 shows a dome projection of a complete panorama view that extends from 0–180 degrees off-center, from our camera system.

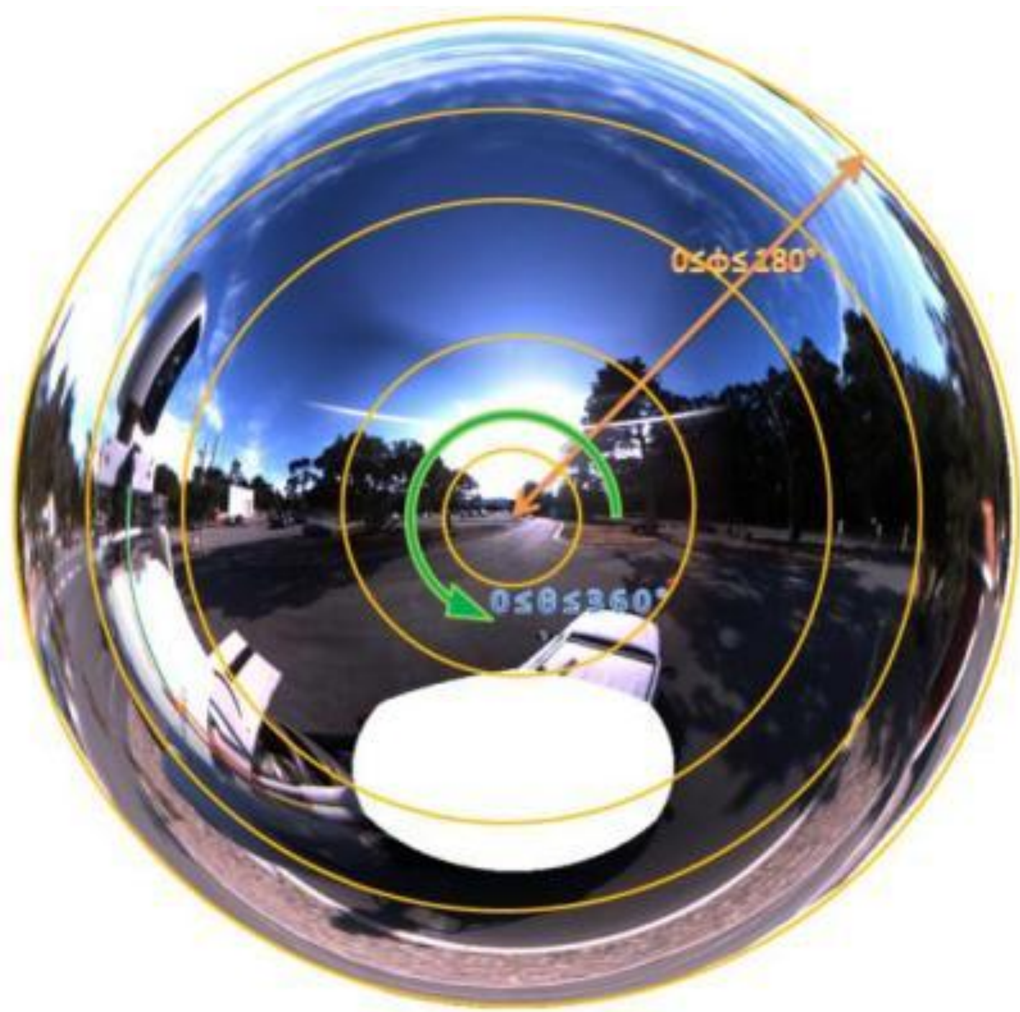


Figure 20 360° view dome projection

Figure 21 shows the human field of view overlaid onto the dome projection, to illustrate the amount of a complete field of view a human can see at one possible moment. This illustrates the limited field that the human visual system can view at any one time. For improved situational awareness, a method of expanding the human field of view could be beneficial.

Figure 21 Human visual field sectioned out of the panoramic dome (After [31])

The human eye also has great dynamic range: natively, the retina is capable of a 200:1 contrast ratio. However, when it adjusts the light input by changing the size of the pupil with the iris, the total dynamic contrast ratio of the eye is approximately 1,000,000:1. When selecting a display method to convey visual information to a user, it is important to keep these numbers in mind.

In discussing display options, we can focus on two main areas: the display technology, and modes of display.

b. Technologies

Display technologies for augmented reality can be grouped into two main categories: optical see-through (OST) and video see-through (VST). These have different attributes and are appropriate for different uses. Their main difference is that OST combines the optical view of a scene with computer-generated imagery, while VST uses a video stream as its background scene, and draws the computer-generated augmentations by changing the pixels of the video frame.

(1) Video See-Through. The video see-through (VST) method is perhaps the easier of the two display methods to implement. The key components are a camera, a computer, and an LCD, OLED, or other video display. The camera takes video images and then replaces or combines some of the pixels in those images with generated graphics pixels. This pixel replacement has advantages such as: easier alignment of view with annotations; complete control over image properties; and allowing the external view to be replaced completely with generated images for greater visibility.

VST form factors can vary, but one distinction involving this type of system concerns whether the camera portion of the system is attached to the user's head, or else incorporates a remote camera, potentially decoupled from the physical pose of the user. This latter case can allow the system to have improved capabilities over immersive ―pure" AR, since the camera could be placed in a location with a better field of view, or even in a position that is more advantageous but perhaps more vulnerable. It also opens possibilities for merging AR with teleoperation of unmanned systems.

There are disadvantages to VST systems as well. One is that current portable cameras have resolutions that do not approach that of the human eye, thus reducing range and detail of the external view. Another disadvantage is the time required to process and render each video frame before it can be

displayed to the eye. This so-called ―glass to glass” delay produces a lag that can result in simulator sickness. Also, if the world is being viewed through a video screen, the screen itself is blocking out at least a portion of the real world, that would otherwise be visible to the user if they were viewing the world without the screen. This means that a failure of the display system could cause the user to be at least somewhat blinded until the problem is cleared. While this could perhaps be quickly remedied by moving the display, the negative effect should be minimized if possible.

(2) Optical See-Through. In contrast to VSTs, Optical See-Through (OST) displays operate on the principle of optically combining the light coming in from the world with an overlay image generated by a computer-controlled source. There are several ways of implementing OSTs: aviation HUDs have used these for decades, but for head mounted displays, these are in an experimental state and only recently have become available on the market.

Optical Combiner: An Optical Combiner is the most basic of the approaches to OST displays: a partially-reflective transparent optical element (half-silvered mirror, etc.) is placed between the eye and the world at an angle. An image source, such as a small LCD screen, is placed off-axis to this view, and partially reflects off the combiner into the optical path to the eye. In this way, the image on the source appears to overlay the direct view of objects in the world. This approach is fairly simple, but has several disadvantages: the image source must be quite bright to be seen in some outdoor circumstances, the image can be washed out by the external view, and the field of view can be limited. Some advances have been made in optical combiners, such as the use of dichroic coatings. These coatings are reflective only to particular wavelengths, and thus can be selectively reflective to the image generator wavelengths while passing much more external light. Another issue with optical combiners is that it is difficult to synchronize the focus of the annotations with that of the viewed objects: one

solution for this problem can be to focus the annotations at infinity, so they are always in focus at normal operating distances, but the implications of this technique have not been fully evaluated.

Virtual Retinal Display: Virtual Retinal Display (VRD) is an emerging technology initially developed at the Human Interface Technology Lab at the University of Washington. In a VRD system, laser beams scan directly across the retina drawing the image directly in the eye without an intermediary display. The VRD improves on the optical combiner method because it provides much greater brightness and contrast capabilities.

Display Masking: One issue common to all optical see-through systems is that they only provide additive color: they can add color brightness to the background, but can not make it darker. This limitation is perhaps not so important for annotative AR, but for simulative AR it is a problem. To render realistic images, we need a way to replace the background with our simulated objects. Just brightening the “pixels” can make realism difficult. Because of this limitation, successful OST systems may require an addition: a “mask display” that blocks out the outside view where the augmentation is being drawn. A description of mask displays is given in “The End of Hardware,” and has not been fully explored [32].

(3) Head-Mounted Display. The stereotypical view of AR has historically involved “Terminator Goggles”: displays mounted over the eyes, like goggles or eyeglasses, through which the user views the world and has information overlaid onto that view by the AR application. This form factor is called the Head-Mounted Display, or HMD. It is a prevailing notion associated with AR in the emerging public eye, but it is not necessarily the best format for all applications.

(4) Heads-Up Display. The Heads-Up Display (HUD) is usually an OST display hard-mounted in front of the user (usually in a vehicle), which allows information to be viewed by the user without taking the eyes off the external world. Although it is the oldest and most prevalent AR display device, it is not usually recognized as such, because its use has previously been restricted to complex combat aircraft. However, this technology is mature and quite capable: AR systems with HUDs are being developed for automobiles.

(5) Head-Down Display. By Head-Down Displays (HDD), we are referring to displays that are mounted in front of the user (also most likely in a vehicle), but not in direct line of sight to the external world. This requires the user to take his eyes off the external world, and precludes an OST configuration.

(6) Handhelds. During the year 2009, mobile phone handset features reached a level that made initial commercial AR applications feasible. Handheld devices with AR capacity typically have a camera on the back and a display on the front: the device is pointed at the scene to be viewed.

3. Sense/Model Environment

A third component that AR systems must integrate is a way of developing a model of the surrounding environment. This is because, even if the pose of the viewer is known, placing new annotations into the scene requires knowing the location where the annotation is being placed. Also, having a model of the environment facilitates accurate depiction of occlusion of objects (say, buildings) by other objects that are nearer to the viewer (say, a tree in front of the building). AR is far from the only use for accurate terrain models, but it is the use most critical to our project.

Three-dimensional geospatial models of active AOs are difficult to produce with fidelity in real-time, however. Simulation environments using actual geospatial data are often of lower quality than custom-made imaginary training environments that do not have the requirement of replicating an actual particular locale. This lack of

fidelity is due largely to an absence of 3D data sensors on the battlefield, and to the vast, unwieldy amounts of data that such systems can produce.

Urban modeling is of interest to this project because 3D models can be used for multiple purposes: in our case, the most pertinent uses are for model-based tracking and for post-mission third-person visualization. There are currently few methods of comprehensively capturing an urban landscape in detail, but much has been done recently to remedy this shortfall [33].

a. Aerial LiDAR

Light Detection and Ranging (LiDAR) is a method for scanning objects in order to determine their spatial features. This involves one or many individual laser rangefinders scanning across the object of interest, and sensing the returning light to calculate distance to the point of impact. This, when coupled with a known orientation and location of the laser, allows calculation of the location of the point of impact of the light. When a great number of readings are measured, they can be composited into a high-detail spatial model of an object. The largest use of this technology currently is the scanning of terrain from the air: an aircraft carries the laser scanner and scans the ground from altitude, capturing enormous quantities of 3D points (a ―point cloud"). This cloud then be used in multiple geospatial applications: it can be interpolated into a raster, which then can be used to generate 3D grid meshes. Both these grid meshes, as well as triangulated irregular networks (TINs), can be created from the scan data and used for various purposes, including virtual environment terrain. Figure 22 depicts such a mesh.

Figure 22 Model generated from LIDAR scan (from [34])

Advantages

- Rapid data collection over large areas
- Serves as a basis on which to overlay additional data for analysis

Drawbacks

- Elevation-focused: limited in providing side detail on buildings
- Interpolation is necessary between points, causing vertical faces to appear slanted and irregular unless extensive post-processing is done.
- Limited asset: Airplane must be scheduled

b. Manual 3D Modeling

3D models and terrain can be generated by artists and technicians using the multitude of products available for this purpose. Some of these products include Blender™ [35], Google™ SketchUp [36], and Autodesk® 3DS Max [37], Maya [38] and AutoCAD, amongst many others. This is the original method of generating detailed terrain models, and can be the most detailed.

Advantages

- High fidelity is available; the artist has almost complete control over the modeling process, and incredible levels of detail are possible
- Optimization measures are readily possible, such as levels of detail (LOD)

Drawbacks

- There is a large gap between fictional terrain and terrain meant to correspond to reality. This can be seen in various game-based simulations used for training as well as entertainment (e.g., VBS2 and ARMA2, which are based on the same engine, but for different purposes). Fictional maps can be continuously updated and improved quickly, but terrain meant to duplicate the actual world has the important constraint of matching the actual locations and attributes of real objects.
- Modelers often are not the users of the models, and do not have personal experience with the location being modeled, which reduces accuracy and fidelity. This process can be improved by using the latest modeling tools that allow construction of models using collections of photographs of the area or building being modeled, but this depends on source photos from operational elements working in the vicinity.

C. EXTANT AUGMENTED REALITY SYSTEMS

There currently are augmented reality systems in service within the DoD and academia, some of which have been available for 30+ years. The DoD systems mainly have been in use in the aviation domain, since aviation has both requirements

and platform capabilities that are compatible with AR systems in general. However, there is much research going on in the DoD with respect to manportable wearable AR systems for the current and future soldier.

1. Aviation Augmented Reality

AR-like technology has been operational in the DoD for several decades. While not what most would consider true augmented reality, some of these technologies can provide capabilities that an AR system affords.

a. Head-Up Displays

Head-Up Displays (HUDs) have been in use on military aircraft since the 1950s: these provide a see-through display system mounted above the instrument panel, which provides key pieces of information to the pilot. Most of these information components are not geo-registered, but some data (such as weapon points of impact) are registered radially relative to the aircraft. This is a rudimentary form of AR.

b. Head-Mounted Displays

Head-Mounted Displays (HMDs) take the HUD idea one step further. Instead of a display fixed to the aircraft in front of the pilot, the HMD fixes the display to the pilot’s helmet. This helmet display is combined with a head-tracking system in order to provide a constantly updated view with spatially and temporally relevant information to the pilot at all times, regardless of direction of gaze. Additionally, this method can incorporate various types of synthetic vision aids, such as thermal or electro-optical sensors, to give the user the capability to see in reduced-visibility environments. A groundbreaking example of this capability is the AH-64 Apache Integrated Helmet and Display Sight System (IHADSS) [39]: this system combines a gimbaled thermal imager/visual camera mounted on the front of the aircraft that can be –slaved” to the position of the pilot’s head, giving the pilot the perception that he can see in the dark. A newer HMD in use in current U.S.

fighter aircraft is the Joint Helmet-Mounted Cueing System (JHMCS) [40], which offers enhanced synthetic vision and high angle employment of weapons. These systems might be adapted to enable AR capabilities.

2. Manportable

a. Land Warrior

Land Warrior [41], seen in Figure 23 is a system to provide the dismounted infantryman the capabilities of FBCB2 integrated with a weapon system and tactical communications.

Figure 23 U.S. Army infantryman with Land Warrior system (From [42])

The Land Warrior system integrates several subsystems:

- A central processing unit running the LINUX operating system
- A weapons subsystem incorporating an M4 carbine with thermal and video camera sights and a multifunction laser rangefinder
- A helmet system with head-mounted display (HMD) and radio headset. The HMD is used to display a tactical map and communications interface, as well as the sight picture from the weapon sights. This allows the soldier to look and shoot around corners and obstructions while remaining under cover
- A navigation subsystem integrating GPS and dead reckoning sensors
- A radio communications subsystem based on the Enhanced Position Location Reporting System (EPLRS)

Land Warrior was first field-tested in 2000. Due to excessive weight and cost (40 lbs. and $85,000 per set), the program was cancelled in 2007. Land Warrior was test fielded to one Stryker infantry battalion deployed to Iraq, however, and enjoyed some success, particularly after it was improved with soldier input. Components deemed unnecessary were stripped out, after which the unit found the system very valuable; particularly for leaders. This success has re-energized the program, and it now is in service with a complete Stryker Brigade.

Advantages

- Tactical communications among infantry soldiers
- Vastly improved situational awareness for equipped units

Disadvantages

- HMD blocks the view of the world for one eye: users tend to flip the display out of the way to see, which impacts continuity of SA
- Battery power endurance is still an issue for extended operations

3. True Augmented Reality

For quite some time, the Department of Defense research community, as well as academia and industry, have been experimenting with fully geo-registered full-blown AR systems for individual use. Some examples of systems follow.

a. Wearable

(1) BARS. The Battlefield Augmented Reality System [43] is a Naval Research Lab (NRL) project to implement a wearable AR system for experimentation. This has been a widely published DoD research project, and has covered human as well as technical factors. This system consists of a wearable computer with HMD, and has been evaluated for forward observer training, among other topics.

(2) MARS. The Mobile Augmented Reality System [44] is a project at Columbia University that also explores wearable AR capabilities. It is significant because it has looked at improving understanding of urban surroundings on the Columbia campus.

(3) Tinmith [45]. The Wearable Computer Lab at the University of South Australia has been a longtime AR research organization. The lab's most prominent project has been the Tinmith AR system. This system is similar to other wearable AR suites. It has been used to implement ARQuake [45],

an AR version of the Quake first-person-shooter game that demonstrated key concepts in live training capability using AR.

These systems, and others like them, have had success in trailblazing AR for possible military applications. However, their performance is not production-ready, because of limitations of displays, tracking, and power supply.

(4) Handheld. Two-thousand-nine was a breakout year for mobile AR, as several mobile phone platforms introduced hardware features necessary for AR: particularly inertial sensors and compasses. This capability allowed the development of a wide variety of phone applications involving AR, using the onboard camera and pose sensors. This has demonstrated the feasibility of handheld AR, although accuracy and precision of pose are not high.

b. Tablets

AR platforms based on more powerful tablet computers have produced some promising results. Using this platform, the VIDENTE/VESP’R [46], [47] system from the Technical University of Graz has demonstrated AR exposure of subsurface utilities in an urban setting. Starting with a pre-existing model, this system can be used to “view” pipes, wires and other subsurface structures, in order to deconflict digging and other utility operations. Such a system is dependent, however, on an accurate, detailed subsurface map.

V. FINDINGS

Over the course of this research, we have identified several areas to which a deployed system as we propose can contribute. Also, this thesis does make some contributions to the military Augmented Reality body of knowledge in itself. The first is identifying distinct modes of augmenting reality. The second is outlining different techniques for providing informational augmentation; and the third is to begin system design and construction of a useable AR prototype.

A. “FLAVORS” OF AUGMENTED REALITY

Upon conclusion of a literature survey, we found that the term “Augmented Reality” has a broad meaning, and has been used to refer to techniques which share some commonality (such as the combination of “real world” with augmentations), but which have different intents. To cope with this, we have named two different categories of augmentation, which illustrate the different intents for the use of these two “flavors.”

1. Simulative Augmentation (SimA)

Simulative augmentations (as seen in Figure 24) have the property of appearing to be “real” physical objects, and have visual properties commensurate with the objects onto which they are overlaid. Consequently, shadows, brightness and other properties of the augmentations must be adjusted to levels appropriate to the objects in view. In addition, the appearance of transparency must be reduced, so that the overlain scene is occluded by the augmentation: if the underlying scene can be seen significantly through the augmentation, then realism can be compromised.

Figure 24 Example of Simulative AR. The HMMWV on the left is computer-generated.

2. Annotative Augmentation (AA)

Annotative augmentations are not meant to be taken as “real,” but rather are used to inject information into a scene, tying pieces of information to the viewed real world. Annotative augmentations also must take into account properties of the scene, but to a lesser extent than simulative augmentations.

Both Simulative and Annotative Augmentation are true AR: in both, the augmentations are spatially registered, and act as if they truly exist at a particular place “in the world.” (This is in contrast to the overlay of non-registered textual and other information onto an external view, such as speedometer HUDs that are

available on some automobiles.) The real difference is the intent of the content: SA seeks to portray simulated physical objects existing in places where they are not, while AA seeks to reveal information about objects that already exist. Currently, there is a great deal of work to be done in human-system integration just in these different areas of information display and modality. We feel this distinction is helpful because it illuminates the idea that both “flavors” are each AR, while also pointing out a significant difference between them. Figure 25 illustrates AA.

Figure 25 Example of Annotative AR. (Background image taken by the author in Baghdad, Iraq, in 2006.)

In the case of our proposed system, Annotative AR is the preferred "flavor" of AR. Simulative AR is not generally applicable, since we are intending to display information that is understood as non-physical in nature. Our annotations must be easily discernable from real objects in the field of view.

B. ANNOTATION TAXONOMY

In the area of content and/or graphics, annotation in AR can be implemented in an assortment of ways [48]. For this project, we identified four general divisions into which annotations can be categorized: Icons, 3D Spatial objects, Hyperlinks and Regional Information.

1. Icons

Icons are the basic form of spatially-registered annotations that can be displayed using Augmented Reality. Icons take a similar form to the icons found on computer desktops: small pictures that graphically suggest the information for which they are a link. AR icon annotation does not necessarily have to include links, however. At their simplest form, icons can be mere spatially-registered dots, but their informational content can increase in parallel with their graphical sophistication.

There are several methods by which we can modify icons in an AR application, in order to convey information [48]. For analyzing and illustrating their application to this domain, we will use the case of attacks on friendly forces as an example case.

a. Color

Annotations can be color-coded in different ways to convey information. One simple example is the convention that pieces of friendly information are colored blue, enemy red, neutral green, and so on. Color can signify categories or quantities: in our application, for instance, confirmed IED icons could be colored red, while suspected IED locations could be orange, and so

on. Conversely, one could color IED attacks based on what specific type of IED was used (known or not), or how many people were casualties of that specific attack.

(1) Spatial Variation. One way we can convey extra information is to vary the color of an annotation across its expanse. This can be implemented using discrete variation (coloring different primitive features of the icon in different colors), or else in a gradient-type continuous variation. Spatial variation must be applied with care, however, because as distance to the icon's location increases, the smaller the icon tends to become, and the greater the chance of losing the detail that spatial variation requires. This issue can be mitigated by not scaling icons purely by distance, but with a variable scaling function (e.g., scale = ln(distance).)

(2) Temporal Variation. Another way we can convey information is by varying the color of an annotation over time. This can include an alpha channel as well, so transparency is an option. Icons can be made to "blink" by rapidly varying either their transparency or their color. This can recreate the effect of red warning lights on radio transmission towers, for example.

A way we could apply this to our IED example is to cause IEDs to blink or change color at a rate related to their suggested "severity": faster blinking IED icons could indicate predicted danger level. One caveat is that red blinking items should probably not be used to indicate information other than that which is dangerous, life-threatening, or of some other emergency nature.

b. Shape

Shapes of annotations can indicate a great deal of information. The basic shape of an icon can communicate the most fundamental details about its content. Militaries around the world utilize this fact, as evidenced by the

abundance of available tactical graphics in their doctrine: just by glancing at a unit icon, we can see easily what size and type of unit it represents.

More complex methods of graphical variation have the potential to convey a great deal more information. An interesting foray into this notion is the 1973 paper by Chernoff [49] on the technique of displaying faces to represent multidimensional data: this takes advantage of the fact that the human brain is structured to recognize slight variations in facial expressions. In this example, faces are drawn with dimensions that are linked to quantities (e.g., length of mouth, spacing of eyes, slant of eyebrows) Trends can be seen easily, for instance, if most of the faces in a given data set are ―happy.” The use of facial features or similar constructs as icons is worth further exploration.

A good application of shape variation is in indicating important quantities. Shape variation is another way that we can vary an IED attack icon in size to indicate the number of casualties.

The size and shape of an annotation also can be varied over time. Thus, instead of blinking, we can make icons swell and shrink periodically. Changes in size and shape of the icon can similarly be tied to a quantity.

c. Textual Content

Another way we can convey information in an annotation icon is to display various textual elements as part of the icon itself. Displaying textual elements is not the same as displaying quantities of written text in a spatial manner. Instead, it means as little as single characters, up to abbreviations and short words can be incorporated into the icon itself. In our example, the icon could incorporate a single letter to indicate the type of attack: ―I” for IED, ―S”for sniper, ―M” for mortar, and so on.

d. Time

Incorporating temporal duration as another piece of annotatable information can be useful. For instance, we can vary the color of an icon over time: to indicate that one attack is very recent and another is old. We could "fade" icons as time has passed. These fading icons would allow the viewer to distinguish the age of particular attacks.

Figure 26 Example of icon depicting an IED (the orange star on the left)

2. 3D Spatial Objects

For some types of information, it is useful to display spatial extent, rather than just point icons. In this case, we can increase the dimensions of the annotations, in

order to create lines, regions, or even volumes. Aside from the increased dimensions, this annotation type is very similar to an icon. Figure 26 and Figure 27 illustrate some 3D annotations.

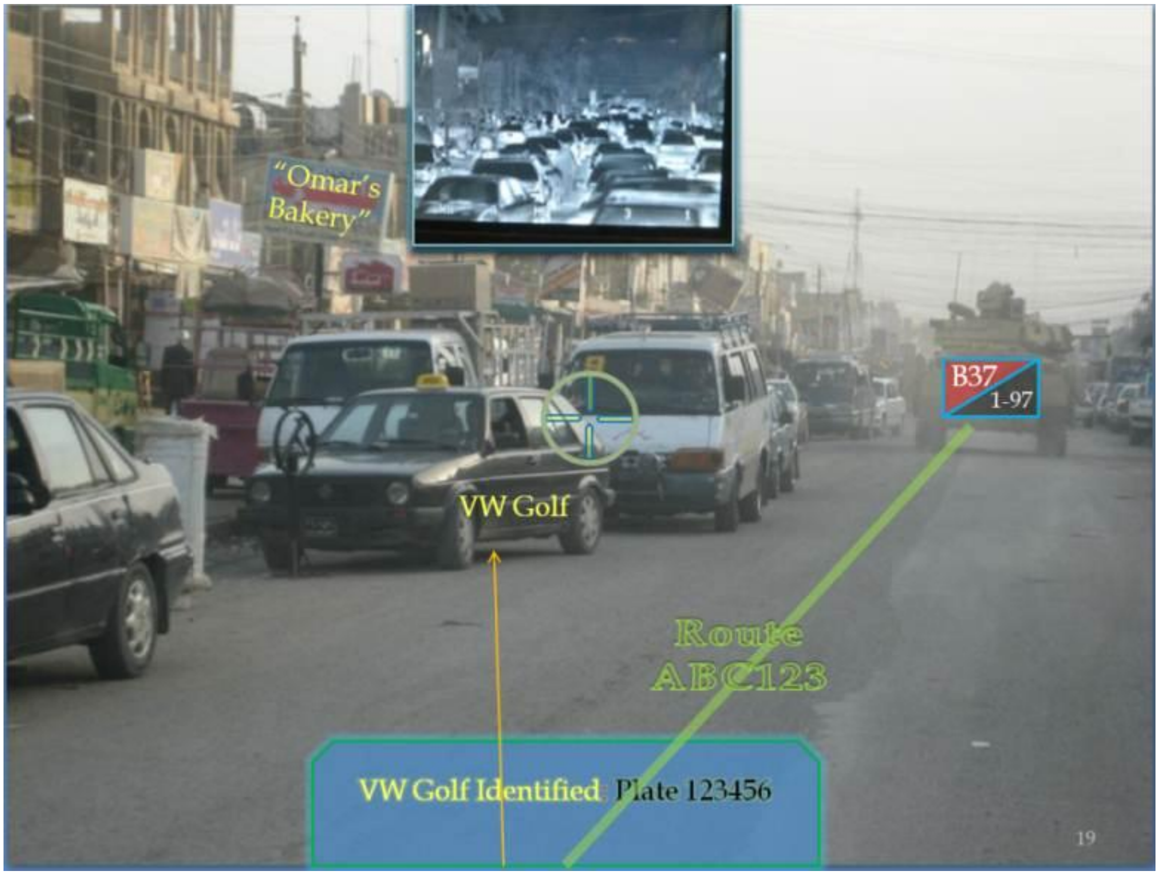


Figure 27 Example of a 3D spatial object (the green line depicting Route ABC123)

3. Registered Hyperlinks

A more complex method of conveying information with AR is to use of icons as “spatial hyperlinks.” In this case, while the icon itself can convey information, it can also serve as a pointer to call up more detailed information on a particular location in space. An example of this today is the popup “bubble” found in Google Earth: an icon is used to convey a small amount of information but then expands when clicked to display textual content (as well as other media options).

This method of employing spatial hyperlinks allows information to be kept at a useable level. If we were to affix text labels onto points in order to describe them, the field of view could quickly become saturated.

Combining icons, links and editable text can potentially provide a rich interface for organizing, editing and presenting relevant tactical information. One way that combined icons can be implemented is as a –3D wiki.” Wikis are Web sites that are directly editable by users from the browser, and are organized using categories and tags, so that they are structured in a net, and not a tree hierarchy. This net structure allows easy insertion of new information. Our proposed use case for adding to a 3D wiki is as follows.

- User —clicks” an —add icon” button, putting the system in —add” mode
- User indicates the object to be annotated, retrieving the 3D coordinates of the point to place the icon
- The icon is —double-clicked,” and a small Web browser pane pops up with a wiki in —add page” mode
- Information on the object is entered (either on the spot, or at a later time).
- The page is closed, and the icon saved: the link to the created wiki page is saved as part of the icon, but this data is kept separate from the wiki database.

Implementing this method allows multimode interaction with all pieces of data: the AR annotation and the associated wiki page. This technique is implemented in a similar manner in geobrowsers, such as Google Earth.

4. Regional Information

In some cases, there is information that is relevant to the user that is particular to user location, but on a much larger scale than would be manageable using icons. An example of such information might be the existence of a local

curfew in a particular neighborhood. This information is spatially associated with that particular neighborhood, but placing one icon in the middle of the neighborhood to indicate this would be a misrepresentation. We could also place icons throughout the neighborhood, but that would clutter the visual screen real estate. A recommended way to display this type of information would be to indicate the area under curfew with a polygon drawn on its boundaries in a geobrowser, and have a —status board” in the corner of the viewer's display that could display text stating —curfew here, 2000–0600 Fridays,” or something similar. This message would only appear for the AR user if he were located inside the boundary polygon. In this way, the information displayed is spatially filtered.

Note that this category of augmentation sits on the border between "AR" and —notAR”: the information displayed is dependent on the position of the viewer, but the annotations are not themselves spatially registered in the view.

C. CATEGORIZATION OF TACTICAL ANNOTATIONS

Over the course of this research, we examined various potential annotations to be displayed by the system: our analysis incorporated relevant military operational experience, and developed some examples of information that could be portrayed through annotations. We analyzed these examples by the following metrics with the goal of evaluating the elements of information by technical feasibility and value to the soldier:

1. Useful Elements of Information/Knowledge

There are innumerable pieces of information that are useful to a leader in combat. Using subjective judgment based on operational experience, we identified some key elements that would be essential to any AR-based tactical knowledge / SA system. We then analyzed their necessary qualities, based on the attributes described in the previous sections, and represented this information in Table 4 . These pieces of information include:

Locations of Friendly Forces: Location of friendly units is of high importance to leaders maneuvering in combat situations, due both to the importance of maintaining an accurate tactical picture of the battlefield, as well as the essentiality of avoiding incidents of friendly fire.

Location of Enemy Forces: The location and disposition of enemy elements in the local area is something that every combat leader wants to know. This is complicated, however, by the fact that the enemy is generally noncompliant with our attempts to track him.

IED Locations (Current / Suspected; Historic): The currently suspected location of Improvised Explosive Devices (IEDs) is of course of great concern to the soldier in combat. However, the historic locations of exploded or found IEDs can be extremely important as well, because attacks tend to occur in places that are conducive to such attacks. This can be a cue to the patrol leader that the IED threat might be elevated when approaching certain locations.

Table 4 Annotation analysis

Elements of Information/ Knowledge		Annotation Content & Metrics								
		Annotation Techique	Update	Duration	Variables	Criticality	Precision	Import. (C+P)	Data Source	Description
Locations of Blue Forces		Icon	Heartbeat	Minutes	Type, Est. Precision, Velocity Vector, Callsign/Channel	4	3	7	Blue Force Pos Updates	3D Unit Symbols
Location of Enemy Forces		Icon	On Command	Minutes	Type, Est. Precision, Velocity Vector	4	2	6	Spot Reports	3D Unit Symbols
IED Locations	Current / Suspected	Icon	On Command	Hours	Type, Size	4	4	8	Spot Reports	IED Icons
	Historic		Static	Static	Type, Size, DTG	3	4	7	Tactical Database	
Sniper Attack Positions	Current / Suspected	Icon	On Command	Hours	Type	4	3	7	Spot Reports	Sniper Pos. Icons
	Historic		Static	Static	Type, DTG	3	3	6	Tactical Database	
Enemy Engagement Zones	Current / Suspected	3D Spatial	On Command	Hours	Range, Type, Origin	4	3	7	Spot Reports	Highlighted area
	Historic		Static	Static	Range, Type, Origin, DTG	2	2	4	Tactical Database	
Routes		3D Spatial	Proximity	Static	Condition, Threat, Last Traversed DTG	1	2	3	Tactical Database	3D Lines registered to the road
Person of Interest	Current / Target	Icons, hyperlinks	On Command	Hours	Personal Details, Threat Status	2	2	4	Spot Reports	Attachments to 3D Icons (hyperlinks to external text box)
	Historic		Static	Static	Personal Details, Threat Status, DTG Last Contact	1	1	2	Tactical Database	
Subsurface (Culverts, Sewer, Utilities), Bridges		3D Spatial	Static	Static	Type, Size, Depth, Condition, Last Traversed DTG	2	3	5	Tactical Database	Lines / Highlighted areas
Host-Nation Facilities		Icon, hyperlinks	Static	Static	Facility Info, Last Contact DTG	3	1	4	Tactical Database	Facility Icons
Cleared CASEVAC Helicopter Landing Zones		3D Spatial	Proximity	Static	Obstructions, Last Cleared DTG	4	3	7	Tactical Database	Highlighted area
Local Cultural Events		Regional Information	Per Schedule	Minutes-Days	Time, Duration, Spatial Extent	3	1	4	Schedule	Announcement Message
Blue Force Events		Regional Information	Per Schedule	Minutes-Days	Time, Duration, Spatial Extent	2	1	3	Schedule	Announcement Message
"Guidons" Announcements		Regional Information	On Command	Hours	Time, Duration, Spatial Extent	4	2	6	Spot Reports	Announcement Message

Enemy Attack Positions (Current/Suspected; Historic): Displaying positions from which the enemy may or has already attacked is very important, because, again, they are good starting places to start when searching for threats.

Enemy Engagement Zones (Current / Suspected; Historic): As in the case of positions from which to be attacked, areas that are more dangerous or vulnerable are good to identify, so they can be avoided if possible.

Routes: Much use is made in combat (urban, especially) of naming routes through areas. These can be closed at times, pending a tactical situation; can be blocked; have trafficability properties which make them more or less desirable on which to travel; have lesser or greater rates of friendly or civilian traffic; and many other properties that could be displayed to the user to help make tactical maneuver decisions.

Person of Interest (Current Target; Historic): Locating persons of interest (whether targets or allies) plays a big role in counterinsurgency combat. Displaying the locations of particular individuals and having the ability to link to historical information on them can assist the tactical leader in many types of activities.

Subsurface (Culverts, Sewer, Utilities), Bridges: Subsurface infrastructure is relevant both as a potential IED emplacement location, as well as playing a role in understanding the state of essential services in an area. This is true as well for bridges, which have other properties such as weight/load class and state of repair.

Host-Nation Facilities: Locations of local civil institutions and facilities are perhaps mundane but an essential class of information that is used on a daily basis in a COIN campaign.

Cleared CASEVAC Helicopter Landing Zones: Pre-identified locations of helicopter landing zones or areas are a critical piece of information for anyone fighting a COIN operation, especially in urban areas, because helicopter casualty evacuation (CASEVAC) is the quickest and best way of getting wounded soldiers to medical

treatment. Not all places in an urban setting are suitable for landing helicopters, and hazards can be pre-surveyed and displayed for both ground forces; and perhaps the helicopter as well.

Local Cultural Events: Local events of daily life among the populace are always good to know, and can be confined to certain locations. Knowing, for instance, that there is a daily curfew in effect, or that it is market day in a particular neighborhood is useful and can be decisive.

Blue Force Events: Friendly force events occurring in the local area are also important to know, and sometimes quite difficult to gather. An example could be a unit conducting an operation in a particular area that happens to be along a heavily trafficked route: units using that route could understand more of the tactical situation, and fratricide could be more easily prevented.

"Guidons" Announcements: “Guidons” calls are quick announcements (traditionally over a voice radio network) to notify all units in an organization on a particularly important piece of information that is time sensitive. If a unit passing nearby or through another unit’s area of operations can automatically receive such notifications based on their spatial location, the information can be disseminated farther than just the land-owner unit’s organic components.

2. Analysis Factors

Annotation Technique: This refers to the suggested type of annotation most suitable to portray the particular element of information. In our case, Icon, 3D Spatial, Hyperlink or Regional Information

Update: This refers to the method by which the annotation is introduced or updated in the system. This can be periodic, such as the periodic “heartbeat,” which continually updates friendly positions on the tactical network; on command, as soon as the information is known; static and unchanging, which applies most to historic events or locations; and per predefined schedule.

Duration: Duration refers to the length of time that a piece of information is most likely of use. Items involved in current operations most likely will expire in usefulness at some time, at which point these same items would then pass into the “historic” category, and exist statically.

Variables: Within the mentioned general elements of information there are sub-pieces of information that are useful to portray or store. Developing annotations that can display as much of these as is useful, without overwhelming the user can add more value to the tactical system.

Criticality: A subjective rating of the importance of the information being annotated, on a scale of 1–4, with 4 indicating the most critical.

Precision: The relative importance of high precision in spatial placement of the annotations. Rated on a scale of 1–4, with 4 requiring the most precision.

Import. (C+P): The sum of criticality and precision, meant to indicate the amount of benefit provided if an AR augmentation were used to display the information, vs. current methods.

Data Source: Presumably, in such a system as we are discussing, data will enter the system in different ways. Because of the potential for huge quantities of information being sent across tactical networks, it may be desirable to have a local replica of an appropriate tactical database on a high-capacity storage device located on the system, which can be synched and updated prior to mission start, in order to confine network traffic to only new or changed data. For this dynamic data, something similar to the current spot report system on the mobile tactical network would suffice.

Description: A description of what a possible instance of the information element could be like.

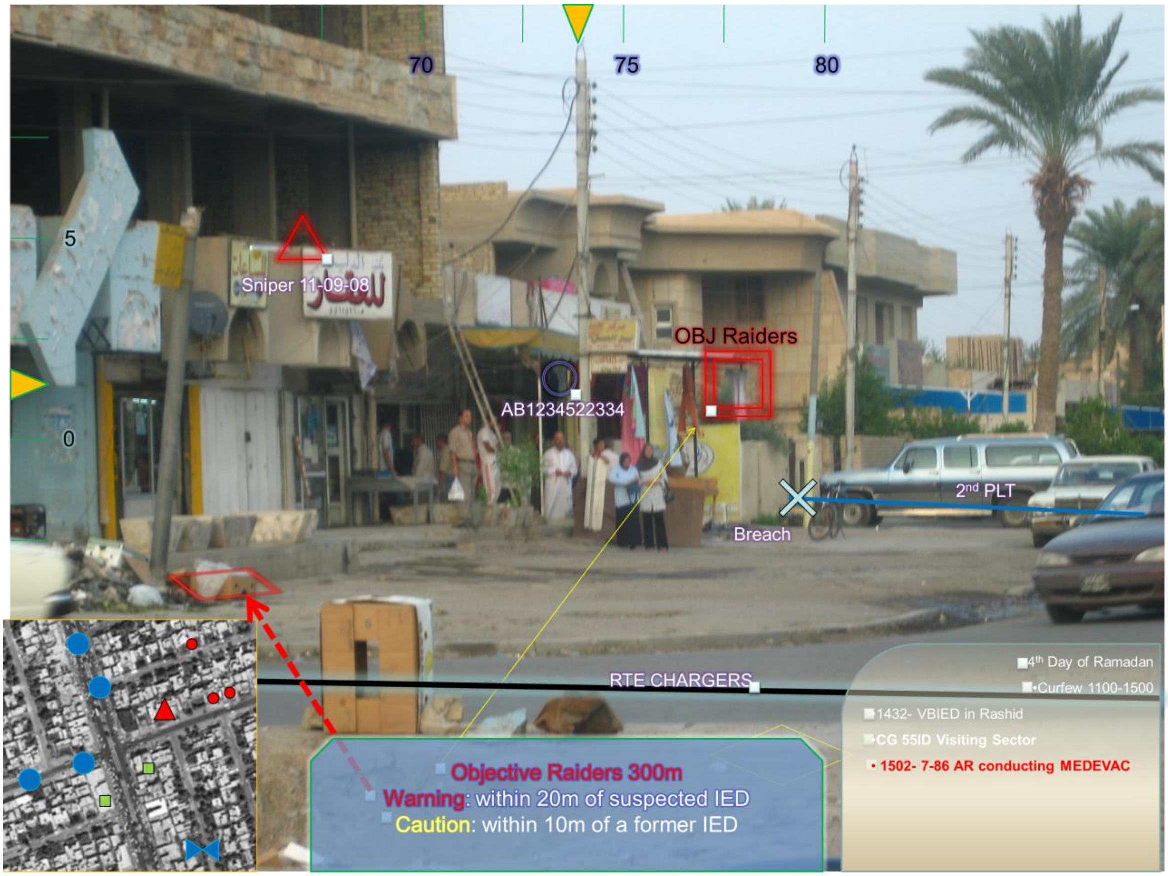


Figure 28 Depiction of a (goal) view through our system, with Annotative Augmentations displaying current and historical tactical information

Example: In Figure 28 , many of the elements of information described in Annotation analysis are depicted: Icons depict a sniper position, an operational objective, and an intended breach point; a 3D Spatial annotation ―Route Chargers," the ―OBJ Raiders" icon has a hyperlink button which will open a Web page with information on the objective; and in the lower right corner, regional information shows current goings-on in the local area. In addition, enhancements are provided to assist in interpretation of the scene, such as an overhead map, text warnings, and arrows to highlight locations of threats.

D. SYSTEM ANALYSIS AND DESIGN

Once an analysis on the desirable requirements for the annotations was done, we then analyzed capabilities and requirements of hardware and software in order to provide an initial concept for a prototype system that would be capable of producing the intended annotations and views.

1. Vehicle Platform

Figure 29 PARPICE-V

The foundation of the PARPICE system is the vehicle platform, or PARPICE-V, which can be seen in Figure 29 and Figure 30. In our case, this platform is a 2005 Toyota Tacoma quad-cab. Our particular vehicle came outfitted with two storage batteries, a power conversion system, and a telescoping mast with associated air compressors, which provides a robust infrastructure on which to build our system.

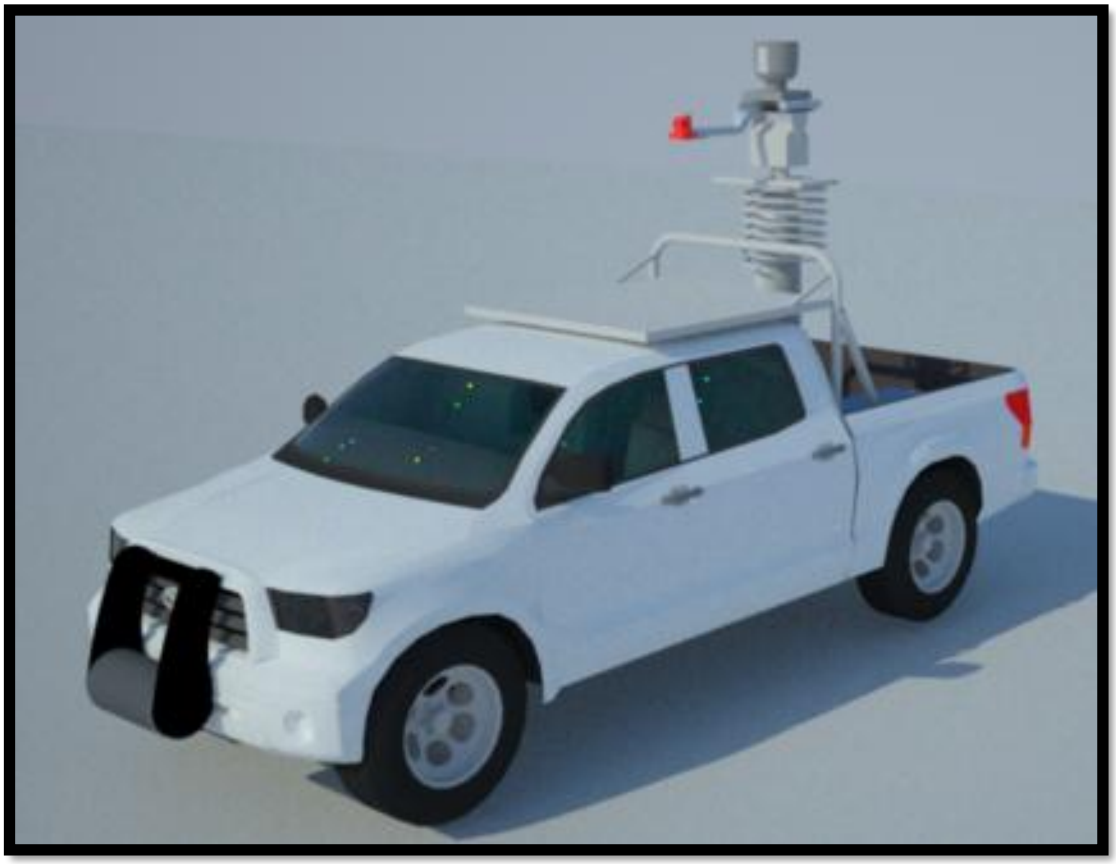


Figure 30 The PARPICE vehicle (rendered). Note the LiDAR and panoramic camera atop the telescoping mast.

2. Desired Functionality

As addressed previously, it is our intent eventually to address two operational problems: the “Knowledge Persistence Problem,” and the “Immediate Tactical (Situational) Awareness Problem.” Therefore, we have identified capabilities that would each address both of our identified problems.

We captured the system functions/capabilities and their relations in the diagram in Functional breakdown diagram. This diagram outlays the identified functional capabilities, as well as the inputs and outputs of each function. Additionally, the physical or software components that implement each functionality group are specified across the bottom of the diagram, similar to the IDEF0 system diagram standard.

In addition to developing the desired functionality, we must simultaneously minimize the negative impact of the use of such a system. This leads us to identify several constraints we must mitigate:

- This system is intended to add capabilities to the soldier, not replace any current capability. Because of this, we determined that the system should not impede the user in any significant way. This caveat means, in particular, that complete system malfunction will not impede mission accomplishment by the user.
- This system is intended to be used in a moving vehicle. Because of this, the components must be robust enough to handle the impact of vehicle vibration and motion.
- A minimal signature is preferred: this system should not add considerably to the vehicle's detectability.

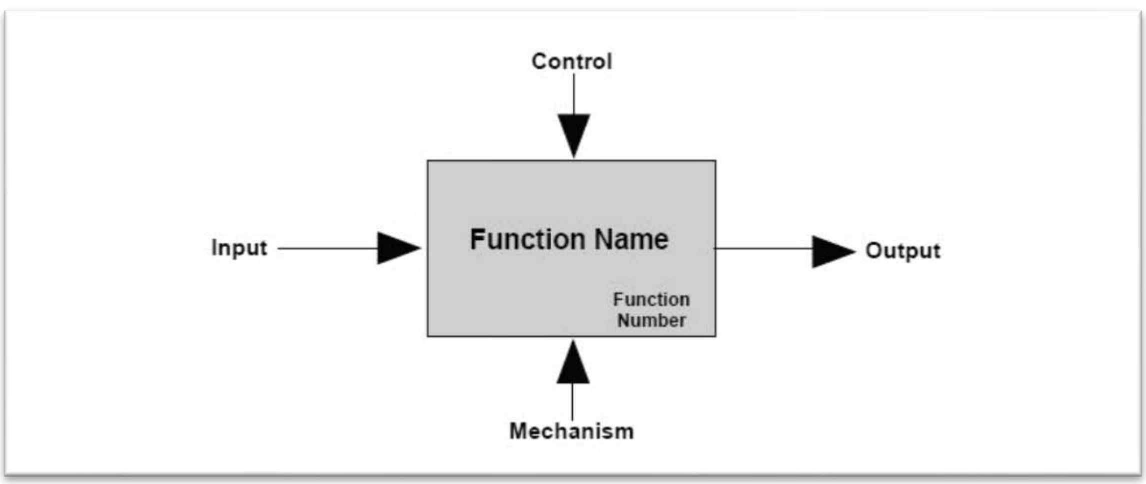


Figure 31 IDEF0 functional model

In light of these desired capabilities and identified constraints, the following sections outline our functional grouping, and discuss the work accomplished within that function, as well as the current status and issues experienced. Figure 32 gives an IDEF0 overview of the functional architecture we have developed.

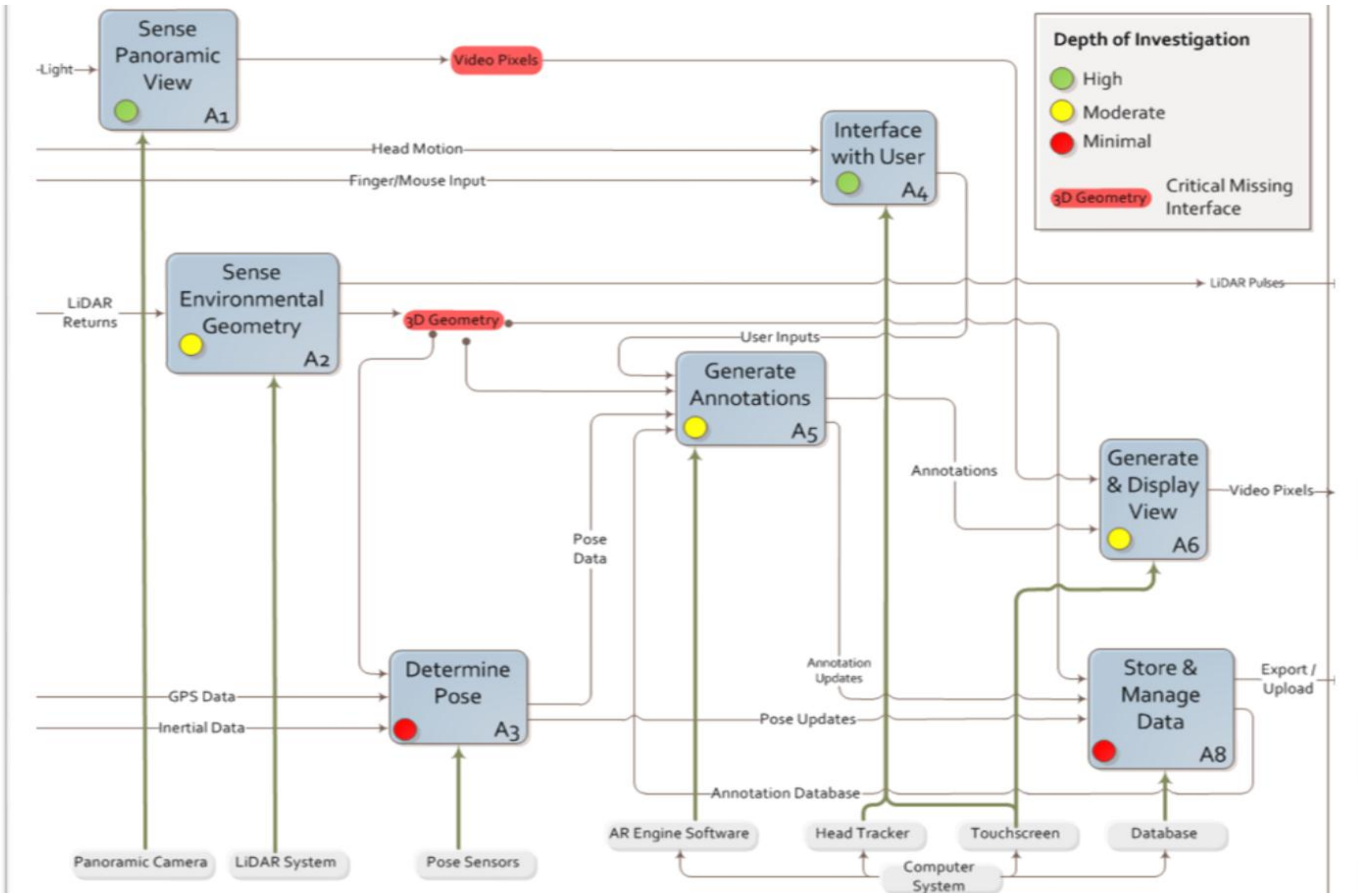


Figure 32 Functional breakdown diagram

a. Sense Panoramic View

This function embodies the capability to provide the inputs to Panoramic Indirect Vision, which we define as the ability for the user to view the external world with an exceptionally wide field of view while under armor protection. This requires the hardware and software to sense panoramic images: Sense light from the surrounding environment in a 360-degree arc around a point, convert this light into pixels, and then composite these pixels together into a panoramic image frame.

Figure 33 Ladybug® 2 spherical camera

To provide the panoramic sensor function, we used a Point Grey Research Ladybug® 2 [50] spherical camera, seen in Figure 33. This camera consists of six individual CCD sensors and lenses mounted in one enclosure: five organized in a band around the body, and one pointed directly up. The cameras stream images to the Ladybug software via a compressor unit and an IEEE 1394b bus, where the individual camera images are stitched together in the

graphics card to produce one large panoramic image stream (see Figure 34), which can then be saved as video files or still pictures. Table 5 outlines Ladybug 2's primary output parameters.

Figure 34 Ladybug panoramic view

The Ladybug 2 camera serves two purposes in the PARPICE system: the first is to provide the user a panoramic view of the external world as part of the video see-through AR system; the second is to record video as the vehicle moves, in order to be used later in texturing an urban model built from LiDAR data.

Table 5 Ladybug 2 properties

Individual Camera Resolution	1024 x 768 pixels
Largest Stitched Image Resolution	5400x2700
Refresh Rate	10-30Hz (hardware dependent)

The Ladybug 2 camera was successfully installed on the PARPICE-V.

Video Capture was successfully conducted on the NPS campus, in synchronization with LiDAR capture, and was saved.

Live video was successfully streamed to the user touch screen while driving.

Our software using the Ladybug Software Development Kit was still limited in capability, particularly in the process for stitching the six camera feeds into a single frame buffer, and then transferring that frame buffer to a texture on the OpenSceneGraph sphere in the Vizard™ environment. However, stitched video was recorded and then played back satisfactorily in our test system.

b. Determine Pose

Pose of the camera and LiDAR points of view is the basic “origin” data to which all other relevant data is spatially registered. This function provides the ability to determine the pose of the point of view: The ability to determine the 3D position (latitude, longitude and altitude) and 3D orientation (heading, pitch and roll) of a first-person point of view.

This functionality is in a very limited state at this time. A delay in hardware availability prevented us from implementing true pose determination. For the purpose of working with stored data in the lab, pose determination was conducted post-hoc using GIS systems and situational knowledge of the test run locations. A partial prototype system was constructed using a Webcam and an Intersense InertiaCube: using a manually constructed 3D model of an outdoor site, and a tripod that mounted the camera and sensor, very promising demonstrations of AR capabilities were conducted, including placing and interacting with icons.

c. Interface With User

This function involves controlling the field of regard of the camera (i.e., pan and tilt) as well as manual selection and alteration of annotation data. In order to do this, the user must be able to select a portion of the surroundings to view, from the entirety of a panoramic view. Additionally, the user must be able to select and edit annotations; must be able to designate one or more of the aforementioned annotations as the item of interest, and query any information with which it is associated and, then, manipulate that information if desired (to include the spatial location of that annotation).

The user interface function was developed as a combination of two subfunctions: tracking the user's head in order to control the field of view on the screen, and accepting mouse events from either a standard USB mouse or a touchscreen overlay.

(1) Head Tracking. Since we utilized a spherical camera, we found it necessary to have a mechanism to control the view being displayed. Normally, this would be done using a mouse, a touchpad, or a joystick, but these are not convenient for use in a moving vehicle (a joystick would be the best of those, but that takes away the use of one hand). A novel alternate method was found, however, through the use of a head tracker. We utilized a TrackIR™ 4 infrared tracker camera [51], in conjunction with reflective head markers to control the view with the head alone.

Figure 35 TrackIR™ camera and hat with reflective markers

The TrackIR device from Naturalpoint works using computer vision techniques to track the reflectors mounted on the user's head. Since the dimensions between the markers are known beforehand, the TrackIR software calculates their positions and moves the view accordingly. With three markers, the system can track a head in full 6DOF. TrackIR originally was intended for use with first-person shooter video games. To allow the player to look around without changing his direction of movement, the rotation rates of the view are amplified: the user tilts his head a small amount to the left, and can move the view in the game around to the left, up to directly behind him. This allows the user to look around the game world while physically continuing to gaze at the computer monitor in front of him.

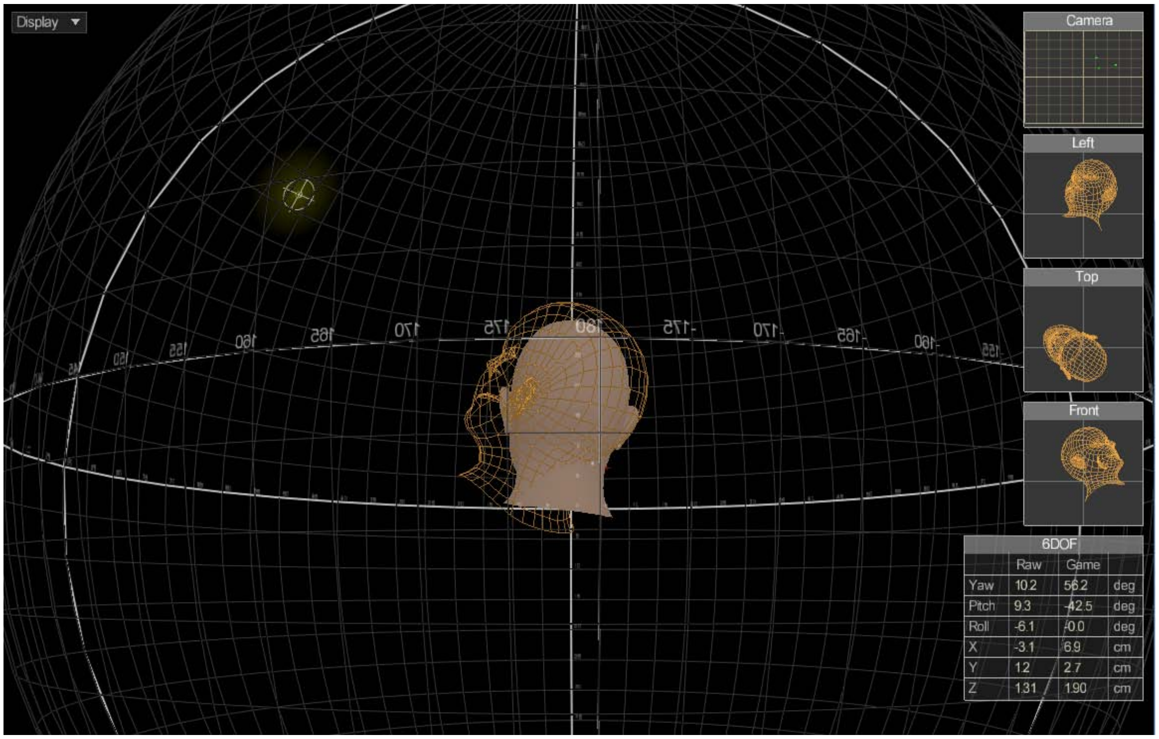


Figure 36 TrackIR 5 software (depiction of head orientation)

In our implementation, we are only interested in the pitch and yaw of the user's head. Translation and roll measurements are not utilized currently, because we are viewing the world as seen from the Ladybug camera's perspective, and this does not translate or rotate with respect to the vehicle. Because of this, we chose to turn off translation and roll tracking in the TrackIR software. This had the great benefit of making the system robust to the motion of the user due to the motion of the vehicle: even if the user was bouncing up and down, the head tracker maintained a good track on the intended pitch and yaw of the user's head. Because we did not have access to the TrackIR API, we took the pitch and yaw output from the tracker and ran it through the TIR2Joy free software package [52], which in turn relies on the joystick emulator program PPJoy [53]. Using this setup, the head tracker becomes visible to the system as a joystick input device.

Investigation of this head-tracking view-control technique has the potential to improve the usability of such a system: the operator has both hands available for other purposes, such as interacting with the annotations on the screen, or talking on the radio. Also, we hypothesize that utilizing head-tracking instead of more conventional methods has the potential to increase the total ease of integration of the camera/annotation video picture into the user's mental situational model.

(2) Object Selection, Editing and Manipulation. For basic command input, we utilized simple mouse interaction events, in conjunction with a touchscreen integrated into an LCD display. The following UML sequence diagrams sketch the concept of the sequence of events of message traffic between different components. Our core software package, Vizard, provides the mouse interaction functionality out of the box.

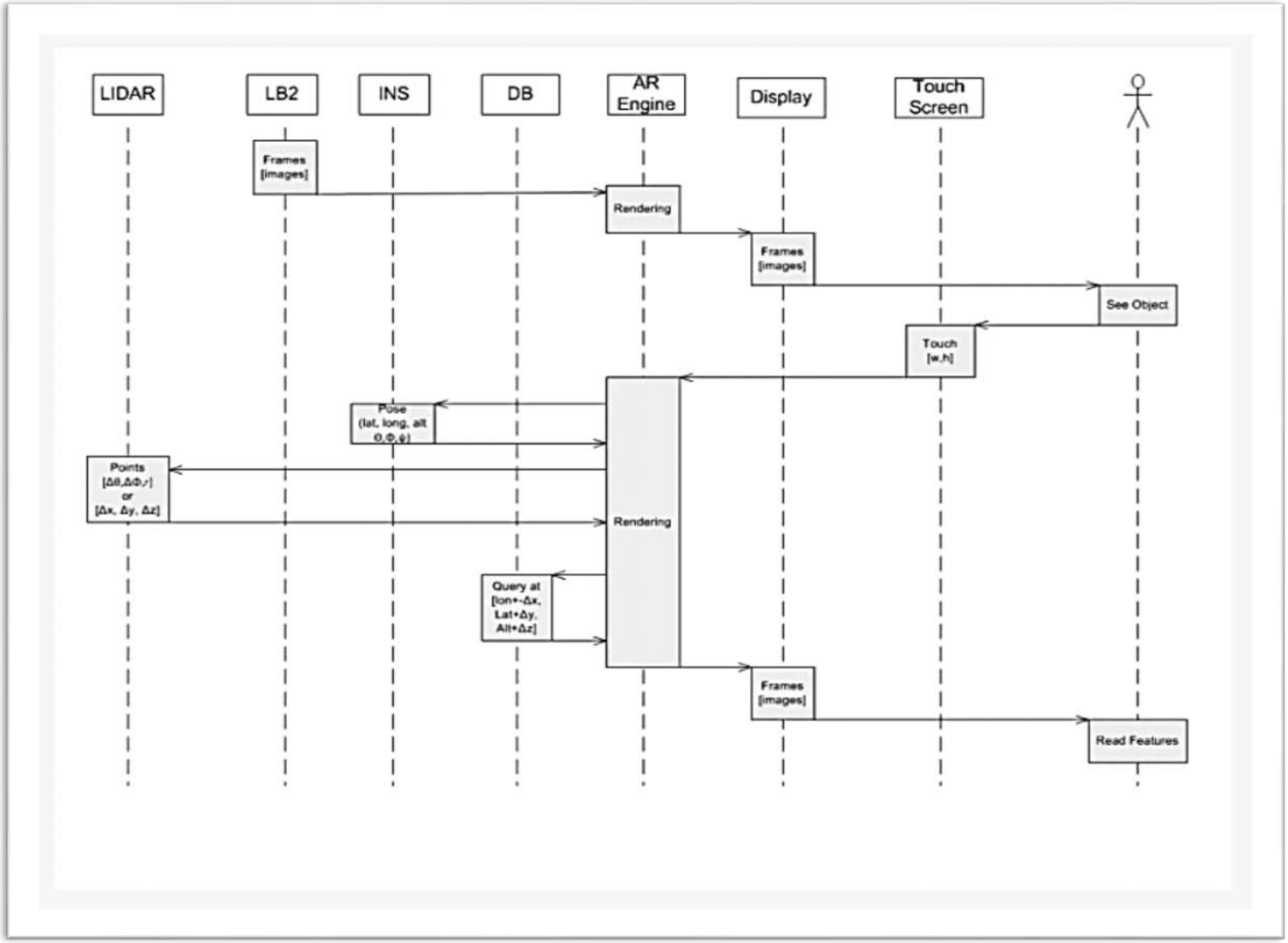


Figure 37 UML2 sequence diagram: Interrogate icon

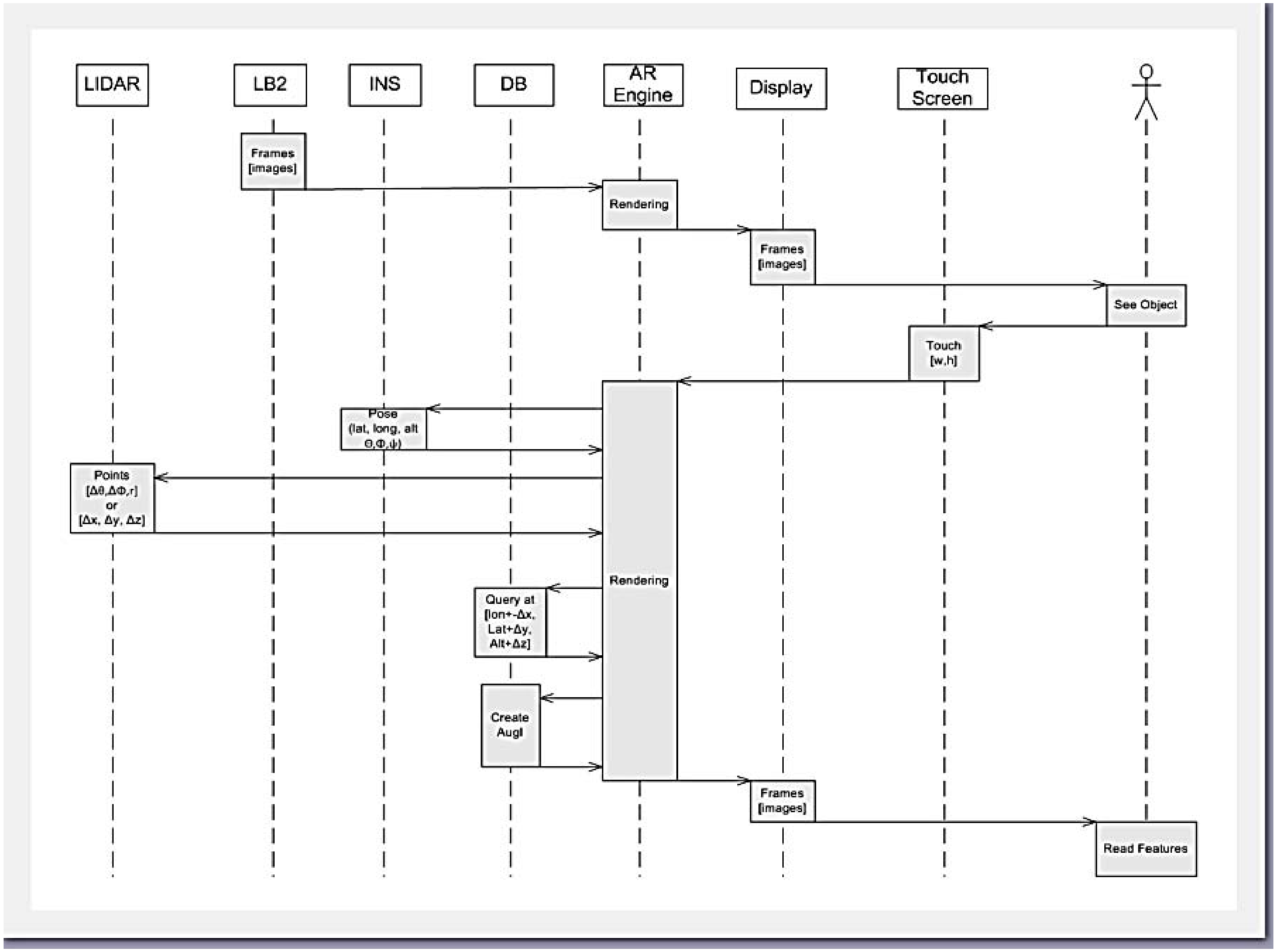


Figure 38 UML2 sequence diagram: Add icon

d. *Sense Environmental Geometry*

This function provides the ability to sense the 3D position in space of the objects in the surrounding field of view around a particular point in space, in a real-time manner, for the purpose of identifying the position of a selected object. Also, it provides the ability to determine 3D locations of a large number of points in a panoramic arc around a point in space, then make this information available for queries on the location of particular points

Our system incorporates a Velodyne® HDL-64E high definition 360° LiDAR scanner [54]. This device consists of 64 laser rangefinders arrayed in a 26.8° vertical fan, mounted in a rotating head. As the head spins at 10Hz, each laser fires 2200 times per rotation, receiving the beam pulse back as a laser return. This pulse is timed, and a distance is calculated from the time of flight. For each rotation, 140,800 points are collected and streamed via UDP packets over an Ethernet cable.

The purpose of this sensor is also two-fold, and in parallel to the images from the Ladybug camera: first, to provide a live depth field for the AR system, in order to determine the depth of objects in the Ladybug image; and second, to scan in order to provide 3D points from which to construct urban model geometry.

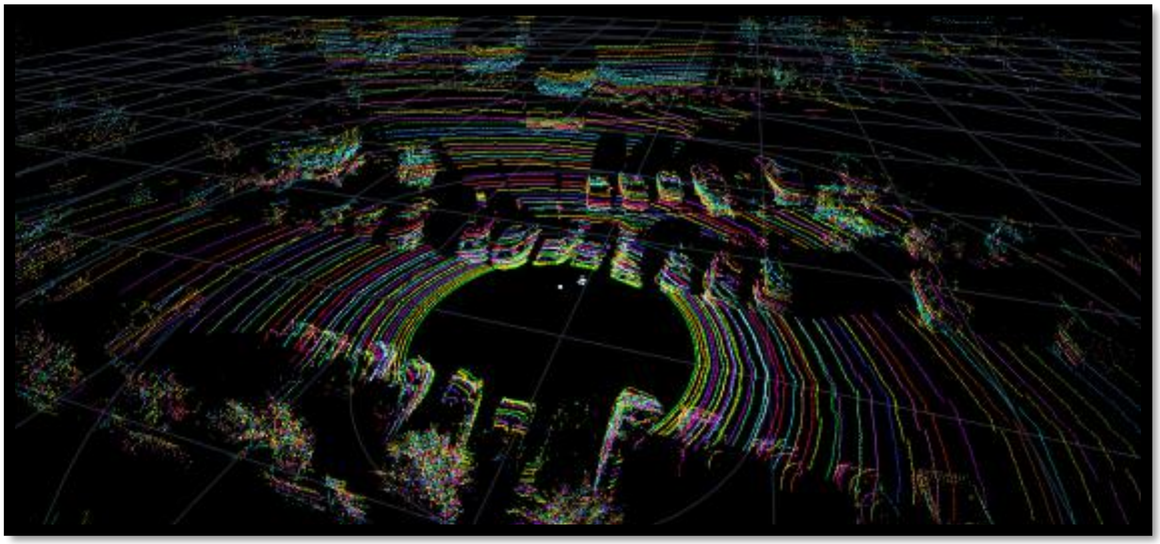


Figure 39   Raw LiDAR returns from Velodyne

Figure 40   Velodyne LiDAR, Including PARPICE-V and OpenSceneGraph-rendered LiDAR points

The LiDAR and Ladybug are simultaneously operational in the PARPICE-V: multiple test runs were conducted on the NPS campus to record synchronized LiDAR scans and spherical video captures, for lab development purposes.

5. Generate Annotations

This function creates the ability to display realistic or semi-realistic spatially registered computer generated imagery on top of a live view of the real world (either optical or video see-through).

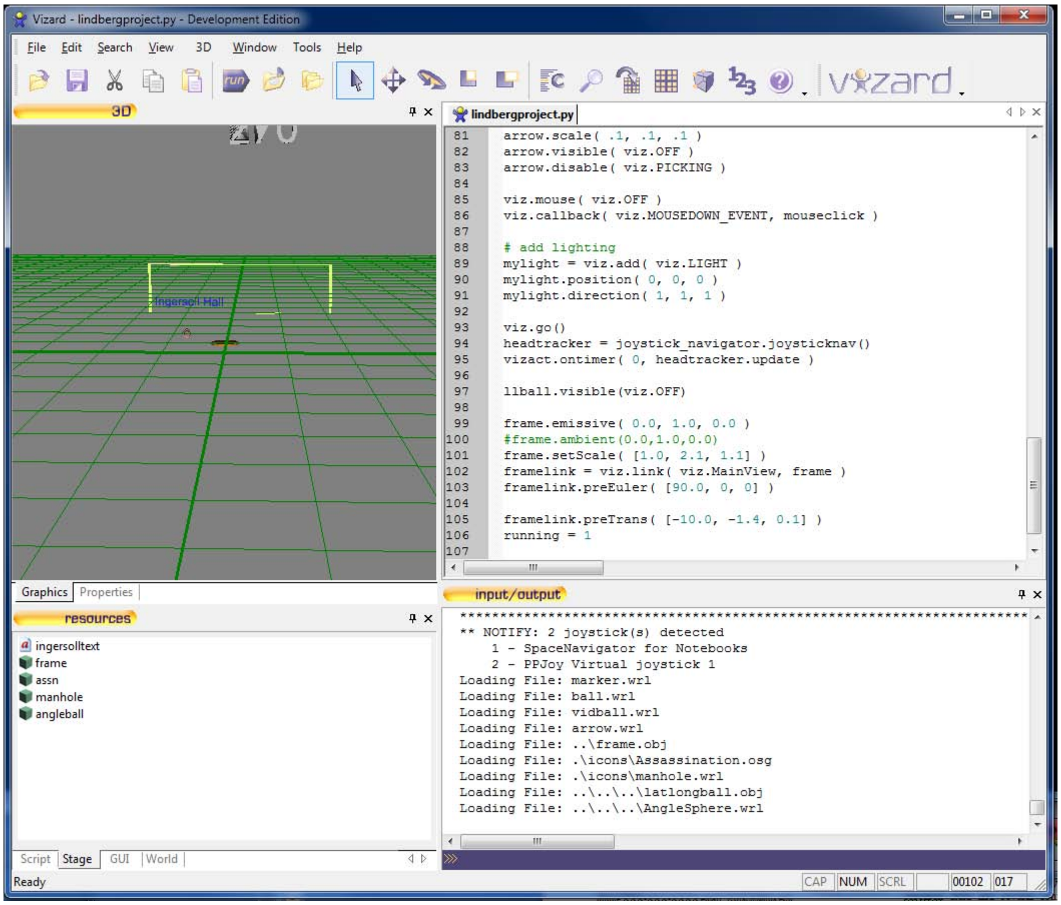


Figure 41 Screenshot of the Vizard development environment

Software Core: The core of an AR system is its software engine. For the sake of timeliness, we chose a commercial software package for this

purpose: The Vizardsuite from WorldViz®, Inc. [55] supplies most of the necessary functionality for our prototype system (see Figure 41 and Figure 42). It provides the following:

(1) Scene Graph. Vizardprovides 3D graphics scene rendering abilities by incorporating OpenSceneGraph. This open source scene graph provides the necessary data structure and manipulation capability to organize, group, add and remove renderable objects in virtual 3D space.

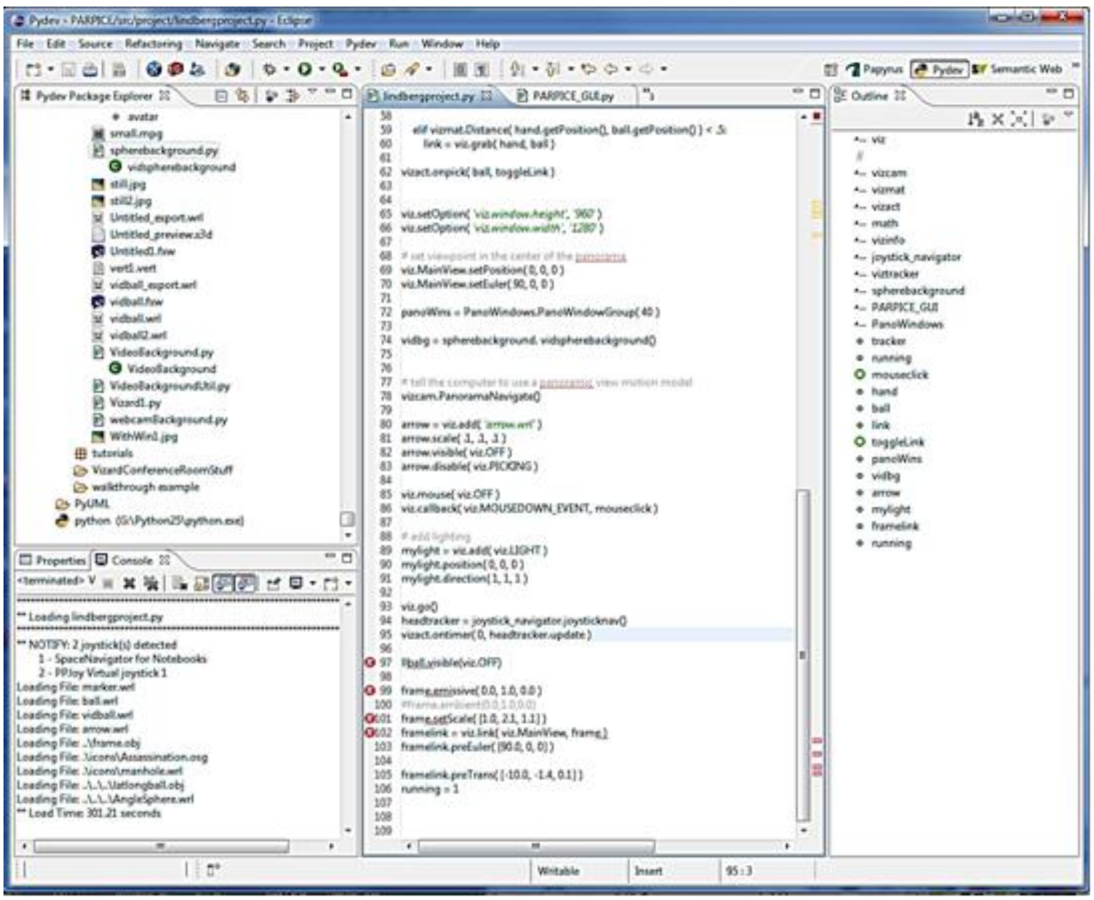


Figure 42 Screenshot of Vizard Code being edited in Eclipse/PyDev

(2) Peripheral Connectivity. Input and output is provided by Vizard's incorporation of functionality to connect to various input and output devices, including joysticks, motion trackers, eye trackers, head-mounted displays,

cameras, and various other devices. This allows Vizard to be the central system for integrating the components of our test system together.

(3) Plug-ins. Vizard comes with a software development kit (SDK) that allows developers to create “plug-ins” for various purposes, including specialized rendering functions, and specialized hardware integration. It was our intention to eventually completely connect the spherical camera and the LiDAR fully with Vizard, although this has not been possible due to time and resource constraints. While we think this is not the optimal solution, the Vizard environment has some benefits in allowing rapid prototyping.

Figure 43 shows a screenshot of our Python code running in Vizard. The top portion of the screen is a live 360° panoramic view from the Ladybug. The bottom two-thirds of the screen is the field of view that the user is currently viewing. The green rectangle in the panoramic view corresponds to the borders of the main view. This screenshot shows how video from the Ladybug appears when textured onto an OpenSceneGraph sphere: in Vizard, we set the sphere to be drawn first, with everything else drawn over it, regardless of position. This effectively sets the live video at infinite distance from the camera, to prevent obscuration of other objects.

Figure 43 Screenshot of the PARPICE test package running in Vizard

6. Generate & Display View

The purpose of this function is to provide the ability to display realistic or semi-realistic spatially registered computer generated imagery on top of a live view of the real world (either direct or indirect). That is, the ability to display to a human eye the aforementioned view, in a manner that retains the visual features of that view; and the ability to display spatially registered information, concurrently inserted into a live view of the environment with which that information is registered

Work Done and Current Status: Because our system is video see-through, we need a monitor on which to display the images with annotations. In

this case, the best method is to use an ordinary flat-panel display, as opposed to an HMD of some sort, or a HUD, for the following reasons:

A Visual See-Through HMD has many drawbacks in a moving armored vehicle. The first is that all electronics tend to break. Due to our intent to be unobtrusive to the user, this makes VST HMDs unsuitable: if a VST HMD breaks, the user effectively is blindfolded until he can take the device off. In combat, being blinded not a desirable outcome. Also, because the VST HMD blocks out the view of the real world, we expect users to be prone to motion sickness.

An optical HMD is also less than suitable in this application, because the optical view of the world is blocked at many angles by the sides of the vehicle. This affects our immediate situational awareness problem, which would fail to be addressed.

A HUD is also not suitable. HUDs have been used in combat aircraft to good effect because, until recently, the weapons of combat aircraft tended to point forward, and their aim points could be displayed on the HUD. (This recently has changed and off-axis capable missiles have been developed, which can fire to the sides of an aircraft. Aircraft with these weapons are equipped with HMDs for the pilots, such as the Joint Helmet Mounted Cueing System.) A crewmember in a HMMWV does not enjoy the visibility of a fighter pilot.

Figure 44   Touch-screen monitor mounted in PARPICE-V

For these reasons, we decided to use a flat panel monitor, equipped with a touch screen in order to interact with the software for purposes other than view control. Issues associated with this display method include screen brightness and contrast limitations in an outdoor environment, as well as screen glare.

Figure 45   Conceptual view of system from user station

VI. FUTURE WORK

Under the assumption that investigation in this project will be ongoing, we propose future targets of improvement and inquiry.

A. RESEARCH QUESTIONS

Separate from the issue of improving the capabilities of the system is the validation of these capabilities as improvements over current systems. Augmented Reality is technologically interesting but, at this time, there are no operational systems to test and compare to extant methods. Currently, we see several areas of research that will require some progress to conclusively determine any benefit to the use of AR.

A key question is, “can AR provide significantly enhanced performance over other methods of situational awareness and tactical knowledge persistence?” Can AR measurably enhance human performance in:

- Accuracy and precision of position determination
- Expansion of the spatial extent of situational awareness of surroundings
- Timeliness and accuracy of querying and recovering information.

Additionally, there are questions of research that are not necessarily AR-exclusive, but deal with the overall capabilities of a system such as we describe. What performance enhancements could such a system provide in the areas of:

- Operational after action review: could the system provide concrete performance data of units in actual combat operations?
- Urban modeling: could the system improve speed and accuracy of 3D urban model creation?

- Direct and indirect fire engagement: could the system improve speed and accuracy of the application of direct fire, and similarly enhance calls for fire support?

B. SYSTEM IMPROVEMENT

Although the system currently is not in a fully operational state, an operational implementation would provide a platform to incorporate other research efforts and add capabilities to the system. In order from easiest to implement to most difficult (or even speculative), some of these are:

1. Incorporate PTZ/Slaved Camera

Integrating a fast pan-tilt-zoom camera is a good step toward making zooming possible in the panoramic image.

2. Increase Camera Resolution

The newer Ladybug 3 has higher resolution, and might improve performance. Also, the compressor unit is integrated, so there is only one piece of hardware.

3. RWS Integration

Integrating the system with a Remote Weapon Station would help address the immediate SA problem. This integration would involve using the PARPICE system as a commander's viewer, and would add one-touch slew-to-cue for the RWS to slew to the point the commander indicated, for engagement by the gunner.

4. Multiple Crew Stations

Investigation into networking the Ladybug to broadcast (or multicast) within the vehicle on gigabit Ethernet would be worthwhile. When combined with the LiDAR broadcasting UDP, this would allow multiple computers to display different fields of view to different crewmembers.

5. Optical Character Recognition

Auto-labeling/annotation can be implemented, allowing business and street signs to be read, located, and added to the annotation database. An extension of this would be to integrate translation software, to allow parsing of local language signs.

6. Change Detection

If we can implement saving video and terrain, then we can potentially implement live change detection for the user: changes in the terrain can be highlighted for further investigation. A necessity for this capability is to filter out automobile traffic.

7. Implement LIDAR Tracking

LiDAR-based tracking is a very important area. Implementing the real-time scanning of terrain would enable live tracking with the LiDAR, as well as model-based tracking that would not require the LiDAR to be constantly activated.

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VII. CONCLUSIONS

The bottom line is that vehicle-mounted AR is feasible. This research has identified several ways that a vehicle-mounted augmented reality system could address perceived gaps in vehicle crew capability.

A. KNOWLEDGE PERSISTENCE

We have identified characteristics of methods of portraying annotative tactical data that can be implemented using an AR system. With our system as an interface with the world, and an extensive networked data system to compile the information collected, knowledge can persist spatially in the place it originated.

Table 6 Knowledge persistence performance comparison w/ PARPICE

Problem: Knowledge Persistence	**Assessment**					Average (1-5, 1=Best)
Solutions	Terrain View	Available On-The-Move	Update Frequency	Spatial-Contextual Info Placement	GIG Integration	
Paper Maps w/ Overlays	4	2	5	4	5	4
Sand Table	3	5	4	4	5	4.2
Blue Force Tracking Systems	3	1	2	4	3	2.6
Web-Based Tactical Information Assets	3	5	2	3	1	2.8
Serious Games	2	5	4	3	3	3.4
PARPICE (Projected)	2	1	2	1	3	1.8

As can be seen from Table 6 , in comparison with existing solutions, an operational PARPICE-type system can be expected to out-perform current methods of addressing the knowledge-persistence problem.

B. CONSTRAINED-VIEW SITUATIONAL AWARENESS

Previous efforts at developing a useful vehicle-mounted augmented reality display and user interface system have not resulted in an operational system to date. We have outlined a system that can provide a panoramic AR display, while taking an unobtrusive add-on approach requiring less sophisticated display technology.

Table 7 Constrained-View Situational Awareness performance comparison with PARPICE

Problem: Constrained-View Situational Awareness	**Assessment**				Average (1-5, 1=Best)
Solutions	Crew Protection	Vehicle Commander Visibility	Weapon System Integration	Spatial-Contextual Info Placement	
Human Gunner-Observer	4	4	3	4	3.75
Remote Weapon Station	2	4	1	5	3
See-Through Turret	2	2	4	4	3
[redacted]					
PARPICE (Projected)	2	2	2	1	1.75

Similarly to the previous discussion, Table 7 illustrates that, in comparison with existing solutions, an operational PARPICE-type system can also be expected to out-perform current methods of addressing the constrained-view situational awareness problem.

In all, an operational system incorporating our functional components has the potential to provide an increase in situational awareness; quicker and more accurate information access and knowledge persistence; better crew survivability and greater avoidance of threats.

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